HANDBOOK

OF

INDUSTRIAL ENGINEERING AND MANAGEMENT

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EDITED BY
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by W. Grant Ireson and Eugene L. Grant

Preface

This handbook will be useful to other people besides practicing industrial engineers and students of industrial engineering and management. For instance, the book will be valuable to persons who have been trained in other engineering fields but who are now engaged in management activities. Moreover, it will help all persons—engineers and others—who require concise reference material on various matters related to industrial engineering and management. People already engaged in industrial management and others aiming at management positions, for example, will find this book a valuable guide.

In contrast to the situation in some of the older engineering fields, the topics to be included in an industrial engineering handbook are not clearly defined by custom. Certain traditional industrial engineering subjects, such as motion and time study, production control, job evaluation, plant layout and materials handling, and tool engineering, for example, obviously call for coverage. Other closely related subjects that have been included are engineering economy, budgeting, standardization, safety engineering, industrial hygiene, and quality control. The trend of the times is toward more and better use of the techniques of statistical inference in solving managerial problems; a great deal of useful reference material in this field is included in the section on industrial statistics.

The trend of the times is also toward a more analytical approach in making many different types of managerial decisions. The section on managerial economics summarizes many of the contributions that economic thinking can make to the formulation of business policies. The section on industrial operations research reflects a new viewpoint toward decision-making and includes a number of case studies. The section presenting a trade union viewpoint on a number of industrial engineering matters gives an extremely helpful picture of certain considerations that enter into decision-making today. The short section on industrial climatology presents useful information, not readily available elsewhere, regarding important factors in certain types of decisions concerned with plant location, construction, and the like.

In the preparation of the handbook sections, the authors have tried to stress general principles and to illustrate their applications to industry rather than merely to describe details of industrial practice. Thus the topic of production control is viewed as a particular application of general principles regarding factory systems and procedures. Similarly the topic of job evaluation is a subtopic in the discussion of manpower management and industrial relations. In presenting industrial practices, the effort has

been to stress the best current practice, avoiding, on the one hand, mere description of average practice, and, on the other hand, the presentation of untried theories.

Most duties of industrial engineers deal in one way or another with efforts to control costs. In a sense, this entire handbook is a treatise on the many-sided subject of cost control.

In general, the handbook sections are presented in readable style so that each section may be viewed as a concise text in its particular field, a text written by an authority on the subject. Thus the handbook is useful for home study and is also suitable as text material for courses in industrial management.

We wish to express our gratitude to the authors of the handbook sections for their helpful cooperation at all stages of this handbook project. We are proud of our contributors and feel that they have done an excellent job of presenting a sophisticated forward-looking approach to industrial engineering and management.

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Ernest Dale is currently on the faculty of the Graduate School of Business and Public Administration, Cornell University. He has been an advisor to the American Management Association, with which he has been associated as Economist and Research Associate for almost ten years. He is an Associate Fellow of the Jonathan Edwards College, Yale University, and is also a consultant on organization, control, and economic problems to a number of companies of varying size. He is an advisor to a number of productivity teams from foreign countries and to the Foreign Operations Administration. He is a member of the President's Committee on Accident Prevention and a consultant to the American Hospital Association. He has been a Columbia University Exchange Professor at the Free University of Berlin, a member of the Harvard Economics Seminar at Salzburg, Austria, and a guest lecturer at a number of the Netherlands universities.

After receiving degrees from Cambridge University and Yale, Dr. Dale worked in companies in both England and America on problems of production, marketing, and accounting. Later he was a member of the Economics Faculty of Yale University, teaching economic theory and accounting. He has taught for many years at Columbia University.

Dr. Dale has contributed numerous articles to such professional journals as the *Harvard Business Review*, the *American Economic Review*, the *Journal of Political Economy*, the *University of Chicago Journal of Business*, and he is also a contributor to the *Encyclopaedia Britannica*.

His books include *Planning and Developing the Company Organization Structure* (translated into French, Greek, Turkish, and Japanese), *Increasing Productivity Through Labor-Management Cooperation* (translated into Japanese), *Preparation of Company Annual Reports, Guaranteed Wages and Employment Stabilization Techniques, The Status of the Foreman in Industry*, and *Source of Economic Information in Collective Bargaining*. He is preparing, in collaboration with Col. L. Urwick, a book to be published by the American Management Association and the Ford Foundation and which will be titled, *The Use of Staff in Organization*.

SECTION

Structure of Business Organizations*

Ernest Dale

1. DEFINITION OF ORGANIZATION PLANNING

Organization planning is the process of defining and grouping the activities of the enterprise so that they may be most logically assigned and effectively executed. It is concerned with establishing relationships among the units in order to further the objectives of the enterprise. The following basic characteristics of organization may be helpful in discussing organization planning:

1. Organization is a *process*. That is

* The following contribution is based in part on the author's *Planning and Developing the Company Organization Structure*, published in 1952 by the American Management Association, 330 West 42nd St., N. Y. 36, N. Y. and drawn on by permission of the editor of the A.M.A., which holds the copyright and from which permission to quote must be obtained.

to say, it is continuously changing as economic circumstances, personalities, and structural requirements are changing. In this sense, therefore, organization is dynamic; it may be compared to the changing scenes of a film. At any one moment, however, organization is static and is represented by the organization chart of the moment. In this sense, it may be compared to a photograph.

2. Organization in its initial stages is a *formal*, mechanistic concept. This is an accepted scientific method in order to eliminate other major influences on the organization structure, such as personalities and economic factors. Once the ideal engineering structure has been built, it needs to be modified by existing personalities; this requires a careful consideration of the *informal* structure of the enterprise. The informal structure is best described by the actual channels of communication, interaction, and power influences within the organization. Although there has been for a long time a division between the schools emphasizing formal organization on the one hand and informal organization on the other hand, enough progress has been made in both directions to make it possible to attempt a reconciliation between the two.

3. Organization is the determination and assignment of duties so as to obtain the advantages of affixing responsibility and specialization through the *subdivision* of work.

4. Organization is a plan for *integrating* or *coordinating* most effectively the activities of each part of the enterprise.

2. ADVANTAGES OF ORGANIZATION PLANNING

There are distinct advantages to organization planning. It is of value in defining, discussing, and evaluating the company's objectives. It indicates, in clear and easily understood terms, where responsibilities lie. The resulting organization chart and manual are like a contour map of a geographical area—at a glance or with relatively little effort an executive can grasp the whole company structure and his relation to it. For this reason, the chart and the manual constitute excellent training devices.

As a consequence of organization planning, top executives are enabled to drop overloads of responsibility and thus have more time to devote to long-run planning, reviewing, coordination, and innovation, or to whatever happen to be the company's most important activities. Representatives of different departments are able to work more closely together in the interest of over-all company objectives.

As another result, executives have a greater opportunity to utilize their abilities, to plan their own activities, and to develop and train themselves and others. Organization planning provides the basis for estimating manpower resources and requirements, and thus enables a company to improve its system of executive succession and replacement. In the process, better promotional opportunities are offered to its younger men.

Organization planning helps to integrate personalities with the objectives of the enterprise and makes for improved human relationships. As a famous sociologist put it: ". . . There is no reason why . . . the labour of supplying society with all the material goods needed for its general comfort should not become both agreeable and attractive. There is no necessity of waiting for the slow action of evolution in transforming human character. The result can easily be brought about by the transformation of human institutions." * Thus conditions may be consciously developed to remove innumerable artificial obstacles to better cooperation.

Finally, organization planning can help to remedy some of the ills common to many business organizations: It may reduce or eliminate duplication of effort (resulting in executive manpower saving); do away with "red tape" (by shortening lines of communication and assigning definite responsibility and au-

* Lester F. Ward, *Applied Sociology* (Boston: Ginn and Company, 1906), p 336.

thority); improve coordination between different functions (such as manufacturing and marketing); eliminate unnecessary functions (checking the tendency of empire-building through a manpower budget or, better still, through financial audits); eliminate friction (through reduction of the number of levels of management and through clearer, more logical and more definite allocation of responsibilities); tend to reduce mistakes by placing decision-making nearer to the problems; improve specialization; and properly balance the expansion of various management functions.

Organization planning provides for continuing adaptation in order to meet changes in people, resources, and environment. It aids in keeping the units of the organization in balance by avoiding excessive or deficient strength among the company's departments. The classic example of over-preparedness is the armored dinosaur who was so well protected that he finally failed to earn a living (the analogy cited by Henry S. Dennison in his path-breaking book, *Organization Engineering*).

We may summarize the advantages of organization planning in the words of the late Dr. H. A. Hopf: "That a business cannot permanently occupy levels of effectiveness higher than those clearly determined by the capacity of its executives is self-evident, but it is not generally understood that the influence of superior organization upon the accomplishments of mediocre executives can raise the enterprise to heights not otherwise attainable." *

3. DETERMINING THE OBJECTIVES AND DIVIDING THE WORK ACCORDINGLY

However small an organization, it must start by determining its objectives. The economic resources of any organization are limited and must be properly utilized if the company is to survive and prosper. This requires a formulation of objectives, an assignment of responsibilities, and a division of the work thus to be performed.

The alternative methods for dividing the work of a company toward the accomplishment of its objectives are numerous. They include, traditionally, function, product, location, customers, process, equipment, and time. It should be noted that in many companies these various bases of division are combined, and are coordinated by checks and balances. But there is usually one predominant type of subdivision of the major company activities, made by the chief executive officer himself, called "basic subdivision," "basic delegation," or "primary departmentation."

The first step in the division of work is the determination of the primary responsibility of the enterprise—that is, the purpose of the enterprise, and the major functions necessary to accomplish it. Thus, in a manufacturing enterprise, production is one basic responsibility; in merchandising, it may be advertising; in public utilities, the maintenance of equipment; in the liquor business, the determination of credit risk; in flour milling, the purchase of wheat.

3.1 BASES FOR SUBDIVISION OF ACTIVITIES

The principal or primary subdivision of the activities of an enterprise may then be divided on the following bases:

3.1.1 Function. Major subdivision by function, subject-matter, or principal activities is found in many enterprises where actual control throughout all hierarchies and over all locations is exercised by the heads of managerial functions—such as finance; production (including plant design, construction and maintenance, purchasing); manufacture; engineering (product design or research, possibly quality control); law (claims, tax laws, corporate affairs); human relations

* Copyright 1938 by Harry Arthur Hopf, New York. Quoted from an address published in the *Engineering Journal* (Canada), Volume XX, No. 12, December 1937.

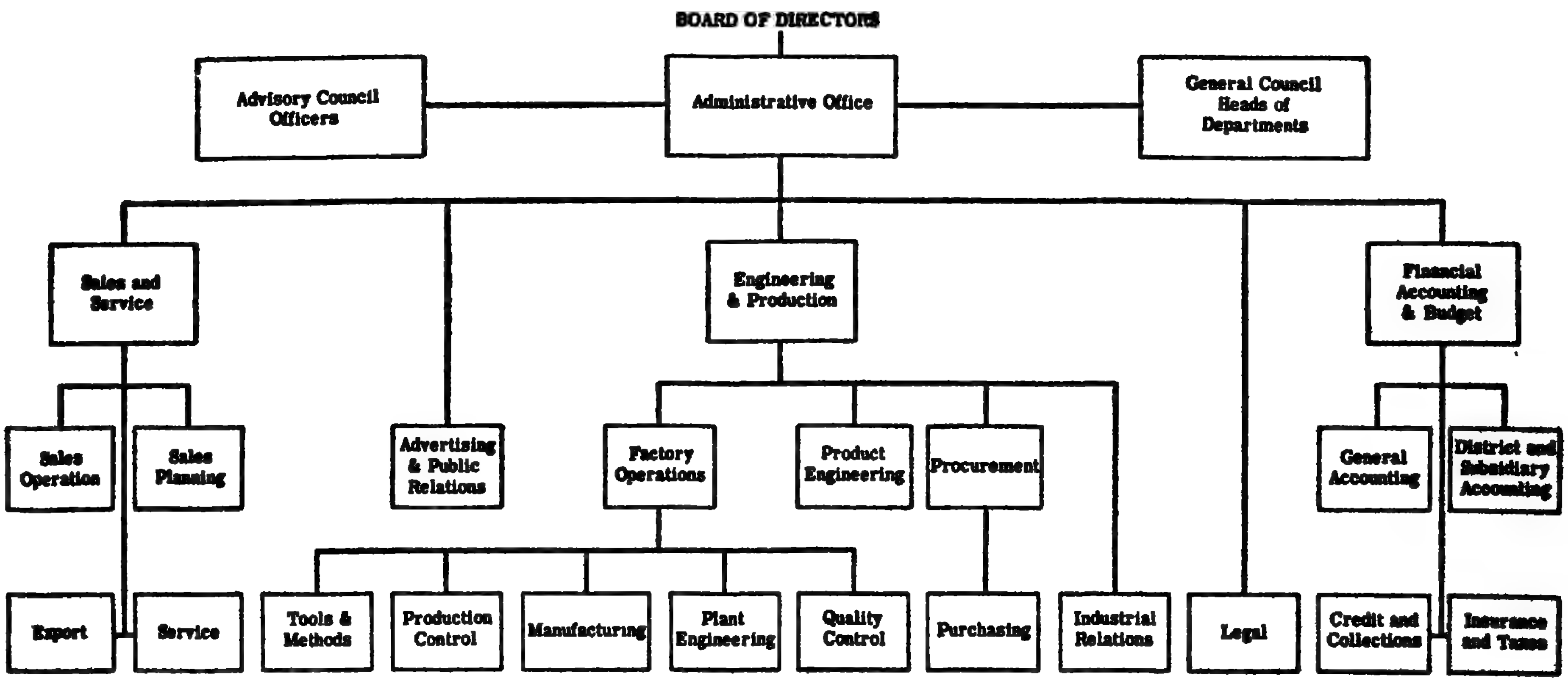


FIG. 1.1 A FUNCTIONAL ORGANIZATION (THE DICTAPHONE CORPORATION).

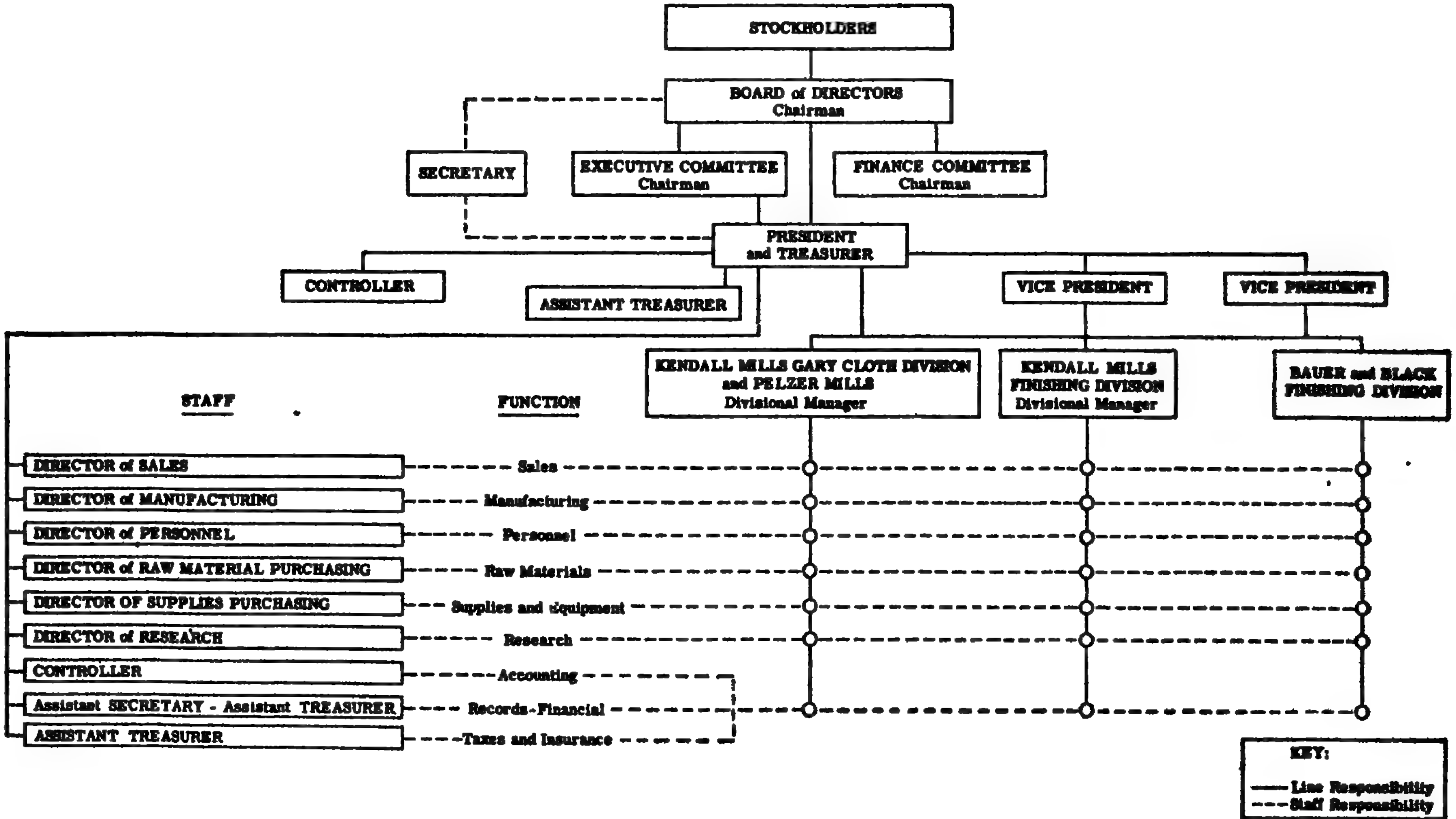


FIG. 1.2 PRODUCT ORGANIZATION (KENDALL COMPANY).

(relations to stockholders, employees, community, government); sales (marketing, advertising). Many companies are so subdivided at the top. This arrangement has the advantages of specialization. More importantly, it should make possible adequate time for basic long-run planning and major decision-making and consultation for those in charge of the major management functions. But it may result in inter-departmental jealousies and conflicts over the limits of authority. It is also subject to considerable conflict among the local plant managers in multiplant organizations. An example of a functional type of organization setup is shown in the organization chart of The Dictaphone Corporation (Fig. 1.1).

3.1.2 Product. Management activities may be grouped on the basis of the major types of products or services marketed, and sold separately. This kind of grouping is used by some large companies manufacturing a diverse product line.

At General Foods Corporation and International Harvester Company, the major subdivisions of work are on a product basis. Other examples are found in merchandising, automobile, chemicals, and meat-packing. Grouping by product has the advantage of bringing together and coordinating in one place major activities required to make a particular product (purchasing, engineering, production, distribution, etc.). Such an arrangement provides a particularly sound basis for decentralization. It may also make possible close control and accounting comparability through central staff agencies.

Even in the "mono-product plants" (as General R. Johnson, President of Johnson & Johnson, describes them), it may be wise to make "little ones out of big ones." For example, at the General Electric Company the refrigerator cabinet is made separately from refrigerator compressor units. Or in the production of locomotives, the cabs and running gear are made in separate sections, and erected and assembled in another section; the rotating units are made in another shop, and control gadgets in still another. In making control gadgets of infinite variety, the necessity for a multiproduct plant really arises.

Figure 1.2 shows the product organization at the Kendall Company, a medium-sized company that is famous for its work in scientific management. It shows a basic organization built around three major products. It also shows in an interesting way the provision of staff services to these line divisions, the operation of which is decentralized, while coordination and control are centralized.

3.1.3 Location (also called territorial or geographical division or departmentation). Under this type of arrangement, all activities performed in a particular area are brought together. It is found in companies serving customers on a national or international scale—e.g., the liquor business, railroads, chain stores, life insurance companies, the overseas branches of motorcar and oil companies. The product and locational principles may be combined, with different factories in different locations devoted to the production of different types of products (e.g., General Motors).

The major subdivisions of oil companies are often on a regional basis, since the natural unit of work centers around the major oil-producing fields. Production and selling or the selling function alone may often be subdivided on a regional basis. The advantage of such a division is that the power of decision-making is concentrated near the source of origin and is all-inclusive, with functional central control. It prevents the losses of efficiency that arise when a company spreads out too thinly. It ensures that careful account is taken of local conditions—an important factor, since the problems of selling may be different in different parts of the country. It makes it possible to take advantage immediately of favorable opportunities arising on the spot. It permits coordination on a manageable scale. It facilitates operation in times of emergency or war. Finally, it provides opportunity for training lower executives in a wide range of activities so that qualified men will be available to fill vacancies in higher jobs.

Figure 1.3 illustrates territorial or geo-

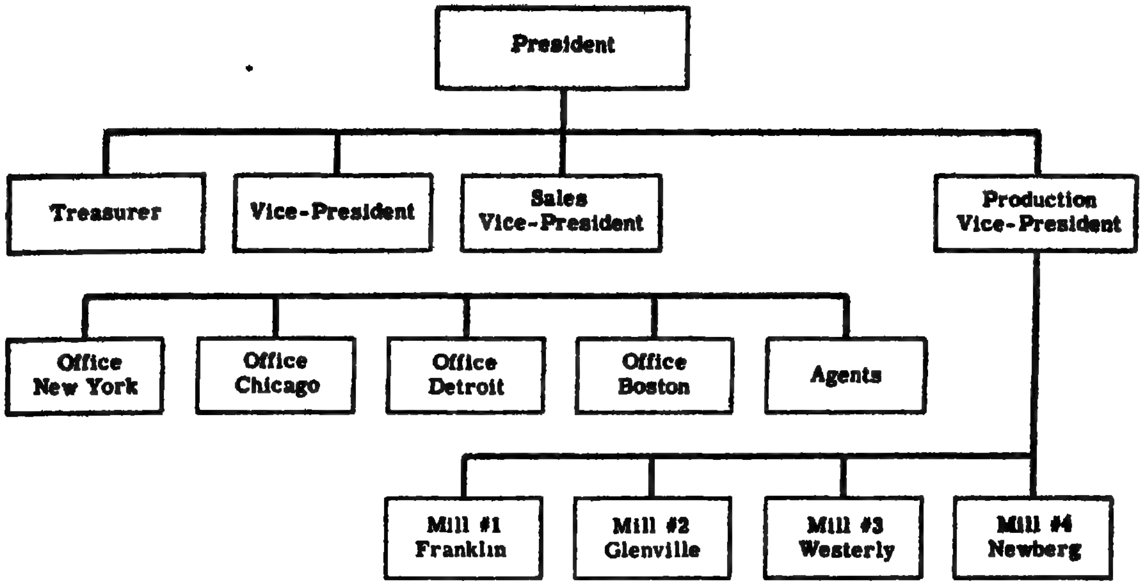


FIG. 1.3 TERRITORIAL DIVISION OF ACTIVITIES (AMERICAN FELT COMPANY).

graphical division of company activities.

3.1.4 Customers. Major subdivision on a customer basis occurs in certain fields —radio and television, for example. Here emphasis is principally on selling programs to individual clients, such as a cigarette company or a soap manufacturer. Lower-level subdivisions on a customer basis are found, for example, on railroads (Pullman and coach travelers), and insurance companies (type of policyholders, sometimes divided by groups of serial numbers).

3.1.5 Process. In integrated textile concerns, major divisions may be made on the basis of operational sequence—e.g., spinning, weaving, bleaching, dyeing, inspection, boxing, shipping. In steel and in men's and women's clothing, subdividing is often based on the process.

3.1.6 Equipment. In certain fields, equipment determines major subdivisions. In a secretarial school, for example, the subdivisions may be determined by the chief instruments whose operation is taught, such as the typewriter, the stenotyping machine, and the comptometer (often identical with process).

3.1.7 Time. Division of work may be based on time sequences, with the work broken down under the categories of planning, execution, and control. Thus the first major business division would be devoted to the formulation of objectives, methods of accomplishing them, forecasts, and budgets. The second major division would be devoted to the execution of the plans, and would correspond roughly to the major operating group in a business. The third major division is devoted to the control of the results of execution in the light of the objectives and plans of the business.

To present an illustration, at one prominent company the general manager has three principal assistants, each of whom is responsible to him for one of the three main aspects of management, i.e., planning, execution, and control. There are three aspects of planning. In order to do a job, one must analyze it carefully and study the available resources. Next, one must balance resources against the job, and design the job to fit the resources. The program must be scheduled on a time basis, and must meet certain set standards of quality and quantity. All these activities are found under the first vice-president. In another corporation, this might be a continuing function of the secretariat of a general policy or planning committee. Although the committee may be made up of certain heads of subordinate departments, the permanent secretariat is in fact the office of the vice-president. Second, gen-

eral management is supplied with a vice-president for operations, charged with the execution of the company's program. He is responsible for the day-to-day coordination, direction, and supervision of the company's affairs. To his desk come the thousand and one issues that demand prompt decisions to expedite the efficient execution of any large and complex program. And, finally, in the jurisdiction of the third vice-president is the function of controllership. His is the job of keeping the progress of the company under scrutiny, comparing it constantly with its program. One might say that this third vice-president serves the other two. He serves the planner by making analyses of the future, and by analysis of past performance that can serve as the basis for future program activities. Obviously, he is a most valuable aid to the general manager, because he is able to make decisions on the basis of all the facts—not merely those that happen to come to him in connection with specific problems.

3.1.8 The *"harmonious overlap."* Another method of work division may be useful, particularly in research work that must be speedily completed to meet competition or fulfill an urgent customer requirement. It can sometimes be applied to a variety of rush jobs.

This method of work division may be best explained by recounting Dr. Alexander Sachs' conference with the late President F. D. Roosevelt in 1939 on dividing the work on the atomic bomb construction:

> F.D.R. was worried whether an atomic weapon could be ready in time to decide the outcome of the war. Dr. Sachs had estimated the project might cost two billions, and honestly told the President that, ordinarily, it would take 25 years to do the job. He explained to F.D.R. that he had searched the history of human thought for an example of how time could be telescoped.
>
> He found the example in music, he says. The composer of music has ways of making time three-layered. Remember the old round you used to sing: "Are you sleeping, etc.?" Three tunes going at once, harmoniously overlapping each other. This, he advised, was what must be done with the atomic project.
>
> "When you start one part of the project, assume you have finished it successfully, and start the next as if you had." That is exactly what was done, probably for the first time with such a huge undertaking. It worked.*

3.1.9 Coordination and balance. An attempt has been made to bring together the various factors of organizational planning in such a way that each acts as a check or balance on the others. In his *Design for Industrial Coordination,*† Robert W. Porter set out a technique for coordinating the basic functions in the field of industrial organization. He set up seven major categories for classifying industrial activities, with three subsidiary classifications for each:

1. The problems of policy, performance, and compensation, identified as technical problems.
2. The problems of planning, production, and inspection, identified as functional problems.
3. The problems of administration, management, and operation, identified as jurisdictional problems.
4. The problems of communication, cooperation, and control, identified as organizational problems.
5. The problems of executive capacity dealing with intellect, volition, and ethics, identified as leadership problems.
6. The problems of employee stimulation, application, and discipline, identified as institutional problems.
7. The problems of expectancy, efficiency, and economy, identified as measurement problems.

The author attempts, on the basis of wide practical experience, to bring out the inter-operation and relationships of the 21 elements of performance, so that staff needs can be reduced, while the coordination process is improved. It is claimed that this plan of division has the advantages of economizing staff services,

* From "How F.D.R. Planned to Use the A-Bomb," by Nat S. Finney, *Look Magazine*, March 14, 1950, p. 25, copyright 1950 by Cowles Magazines, Inc.

† New York: Harper and Brothers, 1941.

improving communication, cutting down jurisdictional problems, and providing better balance in general.

The foregoing are some general guides for determining how the work of the organization may be subdivided, and what consequences may follow. Their specific application will depend upon the special needs of the enterprise. There is no indication from this list that any one way of grouping activities is better than another. If one basis is adopted, then other bases will have to be intermixed. Even when a proper primary basis of dividing work has been decided on, its specific limits must be determined. For example, suppose it has been decided that it will be best to divide sales activities on a territorial basis. This still leaves open the question of how the territories are to be split up. It is not always practical to determine sales territories by geographical boundaries. The problem must be solved in terms of selling a particular article in a particular situation.

For these reasons it is necessary to develop criteria that are helpful in deciding which method of grouping to use. That method should then be chosen which satisfies best the criteria under consideration, and is best adapted to individual needs.

3.2 CRITERIA FOR DETERMINING THE DIVISION OF BASIC ACTIVITIES

In general, the various functions that must be performed to accomplish the objectives of the enterprise should be so assigned as to obtain the greatest possible advantage from the division of labor:

(1) Work should be so divided that the incumbent of a position should be able to become a specialist and increase his knowledge on the particular job assigned to him.

(2) Special abilities should be used to the full.

(3) Groups of people (divisions, departments) should comprise a workable, homogeneous, and separate field of activity. The nature of their work should be similar or complementary (the former is probably more important in the lower executive ranks, the latter more important in the upper ranks).

Three major criteria may be distinguished for dividing work—economic and non-economic criteria, and the size of the company.

3.2.1 Economic efficiency. Economic criteria relate to business efficiency. These in turn may be evaluated in terms of saving money and contributing more to the company's revenue, in the speed or accuracy of transacting business.

That particular grouping of activities should be chosen which will make the greatest contribution to the profitability of the enterprise. This may take many different forms, some of which are discussed in the following paragraphs.

1. In the early stages of a company's growth, the fundamental problem is economic survival. This may require improvement of the production process so that goods will be turned out on time and within the proper cost limits. It may require successful acquisition of sources of raw materials, as in the timber industry and mining. Or, most commonly, it may require acquisition of cash through sales to meet current expenses and to build up a reserve of working capital. These basic objectives tend to become the major function in the business, with the executive in charge becoming in fact the most important official in the business.

Once production or sales have reached satisfactory levels and have become more or less stabilized, they may well lapse into secondary activities, while research and control become dominant. The primary aim at this point may be technical superiority. If this is under pressure by competitors, or if the company itself is forging ahead, this very instability will greatly increase the importance of the technical function—especially if the firm's competitive superiority rests on it. The development by the research or style department of innovations that will accelerate the growth of the company are likely to be primary functions. Or the primary activity, from the standpoint of

profits, may be that of integration, consolidation, and establishment of central control. Once the firm has reached its final stage of growth and is at the point of defending its share of the market, sales may again become predominant.

2. The company may wish to take full advantage of **specialization** and therefore may group together similar functions or specialties. Thus the selling function is often divided into groups of closely related products—in a food company, confectionery products, for example, may be grouped together so that salesmen can devote themselves to selling one product group well rather than dissipate their efforts over many products. Similarly, activities that serve the same purpose may be most efficiently grouped together—e.g., recruitment, interviewing, testing, hiring, and induction may be handled by the employment department, while the employee benefit activities are handled separately by a welfare department.

3. **Lines of communication** may be shortened by a particular type of grouping. Thus specific functions in subsidiary plants may communicate directly with the corresponding headquarters function without going through the local plant manager—e.g., control and auditing.

4. **Duplication** may be reduced or abolished by consolidating a particular function that was previously widely scattered, e.g., the consolidation of the personnel function into a headquarters department.

5. **Balance** may be improved and better operating results attained by combining different parts of a job under several men into one complete job under one man. Joseph B. Hall, President of the Kroger Company, describes such a change in operations as follows:

> Until the past few years, we operated on a functional basis with one man responsible for buying and another man responsible for selling. Sometimes there was friction between these men. If, for instance, merchandise failed to sell, the sales promotion man claimed that the merchandise was inferior; whereupon the buyer would intimate that the sales promotion man had missed his true vocation and should be farming or cleaning the streets. The situation was somewhat like that between the meat managers and the grocery managers; in both cases it was difficult to hold men responsible when each man handled only a part of the complete job.

Railroads have experienced similar cleavages between different parts of the system.

6. The extent of delegated authority may be widened so that lower executives have a greater **power of decision-making.** This has the advantage that people on the spot who are most familiar with the problems can make better and speedier decisions.

7. **Uniformity and consistency** of policy may be brought about. For example, if a personnel department is set up, greater uniformity in pay for similar jobs, and more consistent policies with regard to merit rating and promotion, hiring, and training are likely to result.

8. **Control** may be improved. Work may be so divided that similar units are created so that there is better comparability of selling and production efforts. On the other hand, control may be improved by separating inspection activities from the group—e.g., separation of the financial or auditing function from a subsidiary plant, or by separating credit from sales for fear salesmen will be too easy on the creditors.

9. Activities may be grouped in the department that makes the **most effective use** of them. For example, a company might consider having the production department take over the training function from the personnel department if this is the best way to gain acceptance from foremen and hourly rated employees.

10. **Competition** may be the criterion for dividing activities. Accordingly, the work may be split up into different departments or factories so that the results are fairly comparable. For example, in cement companies the work is distributed to different plants that are usually highly comparable. Sometimes it may be necessary to proceed on the opposite line of reasoning and join two types of work in

order to suppress competition that hurts the total effort of the company.

11. **Job interest** may be severely impaired by over-specialization of individual jobs as well as of whole departments. Where work is divided too finely, with little variation or change, the monotony may obscure the meaning of the job and its relation to the end product, and give rise to job dissatisfaction and quits. Over-specialization is likely to require extra supervision (to deal with the resulting discontent) and an elaborate system of formal controls.

3.2.2 Non-economic factors. There may be important non-economic factors to consider in the division of work. These frequently make for **autonomy** in a particular activity. Thus a special division may be set up to look after special interests connected with the enterprise, e.g., a division on stockholder relations or local community relations. Or the division is created to arouse **attention** to the particular activity—defense work, governmental relationships, safety (Central Main Power Company), executive health, or salary evaluation. At the National Biscuit Company, for example, the head of the Sanitation Department reports directly to the president because the company attaches primary importance to the maintenance of sanitary conditions. Or a special division may be created for a **particular man**—to feather his ego, to "kick him upstairs," to take account of reduced abilities, or to retain some of his services on retirement (e.g., the position of honorary chairman of the board). Division of work may have to be fitted to traditional arrangements within the company. For example, both the production and sales manager may have equal standing in a subsidiary and be given equal powers, but there may be no plant manager. Or the office manager may take over personnel work because there may not be enough of it to justify a full-time division. Or a particular division may continue to occupy an important position within the company simply because it has existed for a long time—e.g., in one company the engineer in charge of bridge-building (the oldest activity in the company) headed up a major division and reported to the president long after bridge-building had become a minor activity. **Preconceived ideas** and principles, and excessive reliance on formality, may also be powerful factors in structuring a business enterprise.

Finally, the **personal interests** or hobbies of the chief executive may play a role. For example, Mac Fisheries were originally added to the Lever soap business in order to facilitate sale of the catch of fishermen of some islands on the West Coast of Scotland in whose development the first Lord Leverhulme took a private interest.

Obviously, not all the factors mentioned are either rational or desirable determinants of the division of work within an enterprise. However, their existence should be taken into account and the reasons for their existence understood before any attempt is made to change the status quo.

3.2.3 Size of company. The final major criterion for dividing the work of the organization is the size of the company. The importance of the chief problems faced by the top management varies as the company grows. Hence the major functions exercised and supervised by the chief executive are likely to change also. This may be illustrated by the Work Table which the great French industrialist, Henri Fayol, drew up* (see Table 1.1).

From this table the following conclusions may be drawn:

1. The most important ability of the head of the small industrial company is technical ability.

2. As one goes up the chain of command, the relative importance of managerial ability increases and that of technical ability declines. Equilibrium between these two obtains in medium-sized companies.

3. The most important ability on the part of heads of large companies is man-

* From Henri Fayol, *General and Industrial Management*. London: Sir Isaac Pitman & Sons Ltd., London, 1949. (Translator, Constance Storres.)

TABLE 1.1 RELATIVE IMPORTANCE OF REQUISITE ABILITIES OF PERSONNEL IN INDUSTRIAL CONCERNS

	Requisite abilities						
	Managerial %	Technical %	Commercial %	Financial %	Security* %	Accounting %	Total evaluation %
One-man business	15	40	20	10	5	10	100
Small firm	25	30	15	10	10	10	100
Medium-sized firm	30	25	15	10	10	10	100
Large firm	40	15	15	10	10	10	100
Very large firm	50	10	10	10	10	10	100
State enterprise	60	8	8	8	8	8	100

* Safeguarding property, avoiding social disturbances in the broad sense and any influence endangering the life of the business.

agerial ability or skills, and the more important the company the greater the place occupied by this ability.

4. Commercial and financial ability play a relatively more important part in the case of heads of small and middle-sized companies than they do in the case of larger companies.

5. As one goes up the scale of industrial concerns, the managerial coefficient increases at the expense of the rest, which tend to even out, approximating up to one-tenth of the total evaluation.

It is clear that the larger the size of the business the greater the emphasis on broad managerial functions, such as planning, forecasting, organizing, commanding, coordinating, and controlling.

3.3 CONCLUSION

The most important criterion for the division of work is that of economic efficiency. This should lead to a specialization, full utilization of abilities, and homogeneity between groups.

Where this criterion is paramount, the basic functions (i.e., those supervised by the chief executive) are those that make the greatest contribution toward profitability. However, the economic criterion, it should be remembered, must usually be modified in the light of non-economic needs. Both need to be fitted to the particular stage of the growth and the special requirements of the company.

4. THE SPAN-OF-CONTROL THEORY

In organization theory, the optimum "span of control"—that is the number of subordinates who can be effectively supervised by one man—is generally set at between three and six. For example:

> "The number of subordinates whose tasks are interdependent who can be directed immediately and effectively by one individual is strictly limited. . . . It should not exceed five or six. The ideal number of subordinates for all superior authorities appears to be four." *
>
> "The average human brain finds its effective scope in handling three to six other brains." †
>
> "It is generally agreed that if the functions that are being coordinated are interdependent and dissimilar, the span of control should not exceed five." ‡

* Lt. Col. L. Urwick, "Executive Decentralization with Functional Coordination," *The Management Review,* December 1935, 356, 359.

† General Sir Ian Hamilton, *The Soul and Body of an Army* (London: Arnold, 1921), p. 229.

‡ R. E. Gillmor, *A Practical Manual of Organization,* Reading Course in Executive Technique (New York: Funk & Wagnalls Company, 1948), p. 12.

While it is conceded that the number may be considerably larger for first-line supervision, most authorities on organization believe that the theory should be applied above that level, and that the higher up in the management hierarchy the superior, the greater will be the need for a small number of subordinates. Thus General Sir Ian Hamilton wrote in an often-quoted statement: "The nearer we approach the supreme head of the whole organization, the more we ought to work towards groups of three; the closer we get to the foot of the whole organization, the more we work towards groups of six." *

4.1 REASONS FOR LIMITING THE SPAN OF CONTROL

Three reasons for limiting the span of control are most commonly advanced: (1) As subordinates are added, there is not only an increase in direct relationships, but also an increase in the number of cross-relationships among members of the group. (2) Human beings have a limited span of attention, which makes it impossible after a certain point to do an adequate job of supervision. (3) The larger the number of subordinates, the more likely it is that they will be dispersed geographically, and hence be more difficult to supervise.

The need for a definitely limited span of control was cogently put by Henry L. Stimson, one of our great administrators:

> When I last held the post of Secretary of War under Mr. Taft, who was a very good administrator, there were only nine Cabinet officers or 10 persons at the Cabinet table including the President. Barring the Interstate Commerce Commission, and perhaps one or two other minor quasi-independent commissions, every administrative function headed up in one of the nine Cabinet officers and went to the President through the departmental head. Mr. Taft dealt with his departments through his Cabinet, and that gave you a sense of responsibility and security that could not otherwise be obtained. Today the President has constituted an almost innumerable number of new administrative posts, putting at the head of them a lot of inexperienced men appointed largely for personal grounds and who report on their duties directly to the President and have constant and easy access to him. The result is that there are a lot of young men in Washington ambitious to increase the work of their agencies and having better access to the President than his Cabinet officers have. The lines of delimitation between these different agencies themselves and between them and the Departments [are] very nebulous. The inevitable result is that the Washington atmosphere is full of acrimonious disputes over matters of jurisdiction. In my own case, a very large percentage of my time and strength, particularly of recent months, has been taken up in trying to smooth out and settle the differences which have been thus increased.*

4.2 REASONS FOR INCREASING THE SPAN OF CONTROL

On the other hand, there are continuous tendencies toward increasing the span of control. These are:

1. The desire of executives to have access as high up as possible, as a means of advancement and a sign of status.

2. The need for keeping the chain of command as short as possible. The shorter the span of control, the more layers of supervision there will be and the longer the lines of communication, with corresponding disadvantages.

There are small companies of 1,000 employees where there are as many as 10 levels of supervision—as many as in the A. T. & T. Company! Thus a man may be the proud manager of the third production sub-district of the Suffolk Division of the Eastern Area in the Northern Region of the so-and-so company. The red tape created by such organizational channels can be comparable to that of a large government office. One company plotted the number of persons through

* *The Soul and Body of an Army*, p. 229.

* Henry L. Stimson and McGeorge Bundy, *On Active Service in Peace and War* (New York: Harper & Brothers. 1947), pp. 495-496.

which an order for a durable instrument went from receipt to shipment—it touched 15,000 people, and the chart plotting its meanderings was 30 feet long!

3. A natural tendency on the part of executives to take a personal interest in as many aspects of their job as possible, the lack of trust in the ability of subordinates, the fear of possible rivals, and the desire for power (as shown by the number of people reporting).

4. The political argument that as many interests as possible should be represented.

5. The danger of overly close supervision, which may discourage initiative and self-reliance.*

The need for a wider span of control is evident in a number of companies. Detailed studies on the span of control at Sears, Roebuck and Company very definitely showed the superiority in operating efficiency of a large span of control, provided subordinates are of high competence and self-reliance. Sears' regional vice-presidents now have full authority over everything in their territories, except purchasing, of course. These vice-presidents report to the president. As a result, Sears' president now has 13 executives directly under his supervision. These territorial vice-presidents, in turn, have even more people reporting directly to them. In addition, other executives down the line have direct access to the president.

Similarly, at IBM one level of management was eliminated entirely between 1940 and 1947, the job requirements of foremen and plant managers were enlarged, and those of middle management were reduced. "Within this simplified organizational framework, the company has apparently found it easier to build teamwork and morale." †

* James C. Worthy, "Organizational Structure and Employe Morale," *American Sociological Review,* April 1950, 178.

† F. L. W. Richardson, Jr., and Charles R. Walker, *Human Relations in an Expanding Company* (New Haven: Labor and Management Center, Yale University 1948), p. 49.

4.3 CRITERIA FOR DETERMINING THE SPAN OF CONTROL

The optimum span of control may be determined by weighing the advantages of retaining managerial responsibility against the gains to be realized by delegating it. The span of control should be extended to the point at which the advantages of delegation (e.g., unburdening of executives so that they may have time for more profitable work) are outweighed by the costs of extra staff, additional supervision, and added difficulties of communication. It should be noted that an increase in the span of control is interpreted here to mean an increase in the delegation of responsibilities.

When the optimum span of control is reached and additional responsibilities still need to be delegated by the executive, it may be wise to add a new link in the chain of command. Thus, if a chief executive has ten different men reporting to him and is overloaded, he may find it advantageous to appoint two men under him to supervise the ten. In this way the span of control is reduced by adding another layer of management. Such action would be advisable, of course, only if the cost of the additional two men and the possible increased costs of communication are outweighed by advantages gained by freeing the chief executive's time.

In the following discussion, we shall merely examine the optimum span of control in terms of the gains and costs of increasing delegation of responsibilities. We shall ask: "Under what circumstances is it worth while for the chief to increase his span of control (supervise *more* executives) by increasing delegation of responsibilities?" In each case, it is necessary to examine the alternative to the problem—i.e., reducing the number of executives supervised and adding another chain of command.

4.4 GAINS FROM DELEGATION OF RESPONSIBILITY

The gains from delegation of an executive's responsibilities to a larger

number of subordinates depend on the contributions he will be able to make to the company's earnings or profits, and indirectly on the degree to which such delegation furthers better relationships. These gains may result from devoting more time to top management work—e.g., developing new ideas, planning, policy-making, looking at company problems as a whole, being available for advice and for help in emergencies, improving governmental and community contacts, and having time to think.

The following factors seem to increase the gains of delegation:

1. The greater the executive's capacity in top managerial work, the greater will be the gains. If his abilities tend to lie in supervision only, the gains will be correspondingly smaller.

2. The less time previously devoted to top management work, the greater will be the gains of delegation. (For confirmation of this observation see the work tables of Henri Fayol, Table 1.1, which show the proportion of time spent on various aspects of management at different management levels and in companies of different sizes.)

3. The less complex the type of work supervised (and the management functions), the greater will be the gains of delegation. For example, in personnel work, personal attention must be given to many matters, and therefore the span of control must necessarily be small. This holds true for many types of research. However, factory workers are not in need of such close attention from their superiors, and hence the span of control can be larger. Again, in some types of activity, such as marketing through large numbers of wholesale and retail branches, under uniform policies with specific delegations of responsibility, the span of control may be quite wide. The same holds true for department heads of general services (building operation, motor vehicle maintenance, purchasing, engineering) where as many as ten may report to a single officer or member of top management. Delegation depends on the type of business; for instance, in a stable business like banking a much larger span of control is possible than in the volatile automobile industry.

4. The fewer the number of different functions supervised by one man, and the less diverse these functions are, the greater will be the gains of delegation. Thus, if an executive supervises seven people, all doing the same thing—seven salesmen, for example—the gains of further delegation will be greater than if he supervised such different functions as finance, personnel, traffic, office management, public relations, and law.

5. The more "mature" the relationships between the superior and his subordinates—that is, the higher the degree of initiative and independence permitted by the superior and possessed by the subordinate—the greater will be the gains of delegation, and, also, the better the mutual relationship.

6. The better-trained the subordinates, the wider their experience in different parts of the company, and the longer their service, the greater will be the gains of delegation, for each of these conditions reduces the amount of direct supervision required.

7. The more competent the aid of "staff assistants" to members of general management, the greater will be the gains of delegation. (See Item 4.)

4.5 COSTS OF INCREASED DELEGATION

The costs of increased delegation, expressed in terms of the increased cost of supervision, may be summarized as follows:

1. The greater the number of additional subordinates reporting to one executive, the greater will be the direct cost of supervision. Thus, if an executive has ten men reporting directly to him, it is obvious that the cost of supervising them will be considerably greater than if he had only five immediate subordinates. But it should be remembered that the direct increase in the number of subordinates may lead to a reduction in the chain of command and in this way may reduce the *total* cost of supervision.

2. The greater the additional number

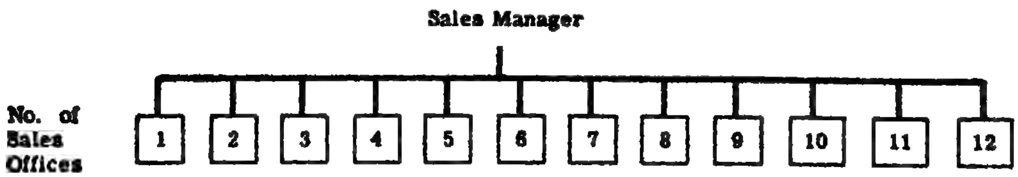


FIG. 1.4 A LONG SPAN OF CONTROL.

of individual relationships between the supervisor and his subordinates, the greater the number of group relationships between the supervisor and groups of subordinates, and the greater the number of cross relationships involving two or more subordinates, the greater will be the cost of supervision. As R. E. Gillmor, Vice-President of the Sperry Corporation, points out: "The number of cross relationships rises geometrically as new subordinates are added. With a span of five the number of direct, cross and group relationships requiring coordination is 41; the relationships rise geometrically with increased span until at 10 there are 1,068 direct, cross and group relationships."

3. The greater the degree and extent of delegated authority, the greater will be the cost of supervision. Also, the smaller the capacity of the subordinates and the greater the possibility of errors on their part, the greater will be the cost of supervision. Finally, the smaller the span of control which the subordinates are able to manage effectively, the greater will be the supervisory cost. As an example, take a sales manager with 12 sales offices reporting directly to him.

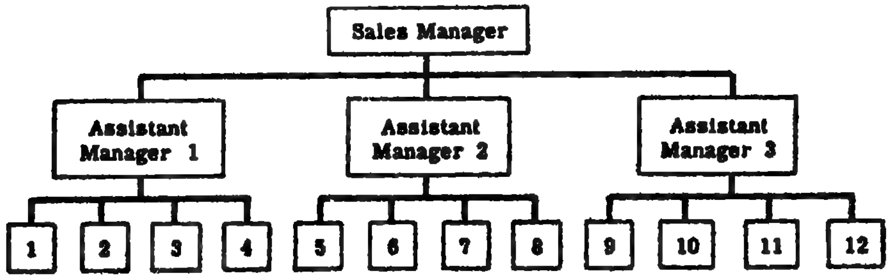
After delegation to three assistant sales managers, the delegating situation is as follows:

In the case of this delegation, the sales manager must weigh the time he gains against the cost of three additional assistant sales managers, the extra cost of supervising them, and the additional costs of longer communication channels (longer time of communication, less accurate transmission of ideas and messages, loss of direct contact, etc.).

4.6 CONCLUSION

In concluding this analysis of the span-of-control theory, it may be well to summarize our major findings. As has been pointed out, some authorities on organization hold the number of men who can be effectively supervised to a number from three or four to seven or eight. In actual practice, the span of control tends to be larger than in theory, both in terms of "supervision" and certainly in terms of "access to," principally because the longer the chain of command, the less satisfactory are communication and efficiency. An ill-advised plan to reduce the span of control can defeat its own objective by creating too many links in the chain of command. This is one of the most paralyzing features of a large organization. The most economical and generally satisfactory solution is one which avoids both an over-long, complicated chain of command resulting in a predominantly "vertical structure," and disproportionately extended organizational units that would eventually result in a "horizontal structure."

FIG. 1.5 A SHORTENED SPAN OF CONTROL.



Of course, a formal limit on the number of subordinates supervised is necessary to make the executive aware of the limitations of time and ability. The span of control may be determined by weighing the advantages (additional revenue) of increasing delegation to a greater number of subordinates against the disadvantages (additional costs). This process of setting limits to the span of control, together with the actual limits that will result, will help each executive realize that he cannot live forever as a managerial superman, continuously operating beyond his physical and intellectual capacity. As a result, he will be better able to replace an able and trusted subordinate who suddenly leaves, or to cope with an expansion to unfamiliar fields. He will also have a margin of safety, or a reserve capacity.

5. REDUCING THE EXECUTIVE'S BURDEN

5.1 THE STAFF ASSISTANT

Increase in a company's size magnifies its problems so that the chief executive may find it difficult to handle all his former duties. Once a company has several hundred employees, some formal planning is usually required to handle its growing personnel problems, to diversify its product line, to uncover new sources of supply and new markets for its products, to streamline production, and to meet the increasingly complicated problems of finance. Rules of thumb, personal experience, and hunches are no longer adequate. The problems arising with increased company size require the services of specialized, technically trained personnel.

The technical responsibility may be delegated by establishing a separate function for the exercise of the technical specialty. However, in some cases it may be advisable to appoint an "assistant to" the delegant. The "assistant to" has no power to act on his own. Instead, he furnishes his chief with information and recommendations which the latter is free to use as he pleases.

The position of the "assistant to" may have the advantage of introducing a new function "under the wing" of the boss. Thus the incumbent of the new function

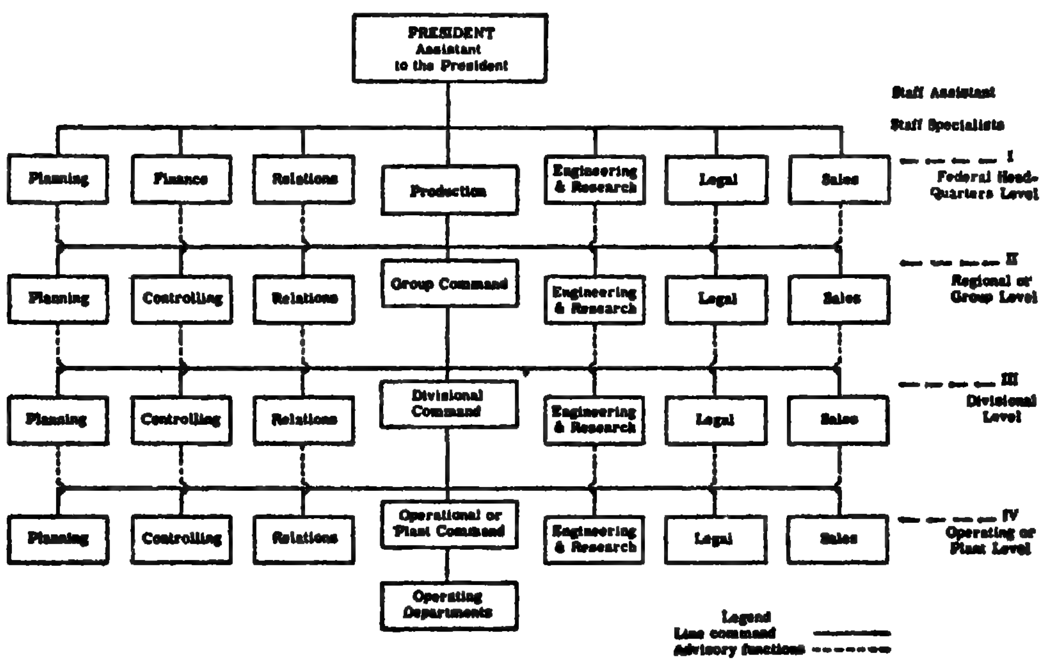


FIG. 1.6 LINE AND STAFF RELATIONSHIPS STAFF ACTIVITIES (NOTE: THIS IS A CHART OF RELATIONSHIPS, NOT ORGANIZATION, OF A LARGE COMPANY).

is given a chance to show what he can do. If put on his own, he might fail because of opposition from those in the established functions, particularly if the other top-management men felt the new function legitimately belonged to them. Thus the head of the new production department might feel that the personnel function should be his, that successful operations require unified control. The separation of these functions might incur the bitter hostility of the production man, who might never give the personnel man a chance to demonstrate that he could succeed. But if the new function remains part of the chief's responsibility, his own position protects it. Furthermore, an "assistant to" the president can learn a great deal more about the company, and more quickly than if he were on his own. Once in possession of company know-how and accepted as a person, he can be invested with personal responsibility.

A widespread complaint on the part of top executives interviewed in a survey undertaken by the author in 20 large corporations was that of excessive pressure of affairs on them. They are working long hours—from eight to 12 hours a day—some staying until midnight in the office, many taking work home at night and over weekends, and most having short and inadequate vacations. Almost all the time of top executives is spent with other people, an increasing proportion with other than company executives—such as government officials, trade association officers, local community contacts, and non-working directors. The result is lack of time on the part of the top executive for adequate contact with associates and subordinates, for rest and recreation, for reading—particularly of a non-business nature—and, most serious of all, lack of time for reflection, for developing long-range plans, and for thinking up new ideas.

Perhaps this grave situation could be relieved by resort to the staff assistant, a device often used, for similar reasons, by the military. General Eisenhower, in interviews with the author, stressed the opinion that businessmen made too little use of the staff assistant. He reported that his own practice was to have at least four or five such assistants, able men closely trained by him and completely familiar with his decision-making habits. They were able to relieve the General of an enormous burden, leaving him free to see anyone with a really important problem—from the journalist with a hot tip before the invasion of Europe to a group of university professors with a grievance.

Similarly, when the job of an executive begins to exceed his capacity, he may consider appointing an "assistant to" himself.

The nature of the staff assistant's area of responsibility is the same as that of his superior or chief; he participates in his supervisor's responsibilities, but none are delegated to him as to a deputy. For example, if he is the assistant to the production manager, he participates in the responsibilities of his supervisor, the production manager, but certain responsibilities are not delegated to him as they would be if he were assistant production manager.

Since the "assistant to" or staff assistant cannot delegate, no one owes any responsibility to him.

The assistant helps his chief in his work. He has been well described as "an extension of his chief's personality," whose job it is to "worry about the problems which worry the boss." The "chief" may be a line executive or a staff specialist. Or he may be the company president. In this discussion, we shall deal principally with the functions of the assistant to the chief executive, i.e., the president.

His status is below that of other executives reporting to his chief or supervised by him. It cannot be overstressed that there should be no dilution of responsibility through the assistant. As one top executive describes his function: "We believe that the chief executive officer should not surround himself with any assistants who in any way diminish the responsibility of the other chief officers of the company. The assistant should

not presume to pass judgment in any other way on any of the principal officers, since it discourages them and makes judgment on their promotion difficult. If he criticizes his chief's subordinates who are his superiors in status, it is the assertion of an authority which he does not possess; and if he criticizes any of their subordinates, he is criticizing them. Further, he is interfering with his chief's authority."

To sum up, in Lt. Col. Urwick's remarks, "The 'Assistant to' is . . . essentially a man who *represents* his chief in matters of administrative detail. His functions are limited to study, research, analysis, recommendation and, above all, to helping his chief to get things done by handling the publication of instructions, etc., watching the organization, and foreseeing and forestalling any failure in coordination between the specialists and the 'line.' He has no executive duties."

5.2 QUALIFICATIONS FOR SUCCESSFUL STAFF ASSISTANTS

In his studies the author found that the staff assistant requires technical competence, discretion, high analytical powers, and ability to present his material effectively in speech and in writing. He must unfold his activities slowly to begin with and win confidence. He should be free from organization politics and give his views on the basis of the merits of the problem. He must gain top-management support so that his efforts may bear fruit. He must be able to "live with" his superior successfully and have a good sense of timing. On their part, line executives must learn how to use staff assistants. This requires, among other things, the ability to listen.

5.3 POSSIBLE ACTIVITIES OF STAFF ASSISTANTS*

The activities of staff assistants may vary in importance from the equivalent of those of an office boy up to activities of a vice-presidential character. *Major activities* may include, in rough order of importance:

1. Coordinating work by bringing together the parties concerned, clarifying misunderstandings, collecting and disseminating information, acting as secretary for coordinating committees.
2. Collecting, analyzing, writing up top management policies, plans, and procedures.
3. Economic and market research, study of competitive conditions, governmental regulations.
4. Screening visitors and requests to the chief executive or top management.

Minor activities may include:

1. Design of management control reports.
2. Design and installation of interdepartmental procedures, leaving intradepartmental procedures to be handled by departmental staffs.
3. Plans for reorganization analysis, preparation of recommendations, preparation of organization manuals and charts, and keeping them up-to-date.
4. Part-time functions like public relations or personnel activities in smaller firms. The staff assistant may not exercise these functions himself, but may merely see to it that they are properly carried out.
5. Working out and suggesting methods of office improvement; control over internal reporting systems, forms, space, and office equipment. (These functions are, of course, frequently performed by the controller, purchasing director, office manager, or industrial engineer.)

In connection with these activities, two different types of "assistants to" must be distinguished. One type performs a function not performed anywhere else. The other type performs a function that is being carried out elsewhere. For in-

* This discussion is partially based on interviews and on E. W. Reilley's "Why Short-Change the Chief Executive on Staff Assistance?" in *Personnel*, 1947, 85-88. See also Henry E. Niles and M. C. H. Niles, "Assistance in Coordination," *Personnel*, August 1938, 35-36, in which the authors discuss what the staff assistant may do and what the staff assistant should avoid.

stance, if a company officer has an assistant to do economic research, with no such work being done anywhere else in the company, there is no problem of duplication. However, if there is a department of economic research in the company and the president has an assistant to go over the material produced by that department, dispute and confusion may result from the lack of clear-cut responsibility.

5.4 ADVANTAGES

The advantages to the chief executive or a top vice-president of having an assistant include:

1. Reduction of the burden of work. This may make it possible for the chief executive to see people, to do some quiet thinking, to extend his span of control (if necessary) or to supervise his present subordinates more satisfactorily, and to supplement his technical competence with administrative and human relations competence.
2. An improvement in planning and coordination.
3. Better utilization and continued application of outside counsel.
4. Training for the assistant so that he may acquire an over-all point of view of the company's affairs; learn how to persuade others; have the opportunity to observe and to be observed; and ultimately, perhaps, be in a position to take over a managerial function.

Staff assistants may be particularly helpful (though this is not necessarily the case) in small firms, under rapidly changing conditions (increase in company size, seasonal and erratic fluctuations), in geographically dispersed enterprises, in organizations having long chains of command, and in situations in which the line executive is newly appointed—especially if he is revitalizing an established company. At his best, the staff assistant develops analytical ability, practical application, sincerity, and enthusiasm for the company to a point where all his actions make him an asset to his superior and to the company.

It is General Eisenhower's belief, as he told the author, that business has overlooked an important opportunity to increase the effectiveness of the chief executive through a larger and abler staff of assistants to reduce his load, making it possible for him to devote himself to broader issues and closer contact with his men and with others. The experience of businessmen with the armed forces seems to show that this is the principal lesson they have learned from the military.

5.5 DISADVANTAGES

Among the disadvantages of having "assistants to" is the confusion that frequently occurs regarding the nature of their responsibilities. There is also the danger that the assistant may substitute his personal opinions instead of representing his chief's views—for example, he may put obstacles in the way of the chief's seeing individuals whom he really wants to see. Line men may resent advice from someone who is their junior in status (and probably age). Such matters as executive job evaluation and reorganization cannot be wholly entrusted to the "assistant to," if he is at all involved in or susceptible to company politics. Moreover, there is danger that the assistant may have more access to the boss than the "doers" or line executives who are out performing their jobs. Worst of all, perhaps, a businessman may be deluded into believing that his capacity for decision-making is multiplied in proportion to the number of assistants working under him.

Some feel that the training afforded by service as a staff assistant can be better provided through rotation, staff meetings, and personal development plans. The opposition to the "assistant to" centers especially on the objection that the assistant too often becomes the executive's interpreter, confidant, companion, errand boy, paper dispatcher, informal contact man, spy, whipping boy, or assumes the role of the "grey eminence behind the throne."

For these reasons, a number of companies avoid the appointment of an "assistant to" or even an "assistant manager" (who takes over some of the responsibilities of the manager in a "one-over-one" relationship) unless the appointment is clearly temporary and made primarily for training purposes. Some maintain that a good secretary can render most of the services performed by the "assistant to" without giving rise to many of the problems of relationship just mentioned.

The issue between the proponents and opponents of the "assistant to" is sharply drawn. The choice depends on the individual case, with due consideration to past company experience, economic feasibility, and the personalities involved.

5.6 DIFFICULTIES IN USING "ASSISTANTS TO"

The following typical troubles have emerged in case after case:

1. High executives had no experience of using "assistants to" as general staff officers.

2. Consequently "assistants to" were appointed:

a. Without any definition of their duties—"Just come into my office and see where you can be of help to me."

b. Without any definition of their relations with other executives—"You may find Mr. Smith a little difficult, but you'll know how to handle him."

c. Without careful selection.

d. Without any special training.

e. Without adequate experience of "the line"—e.g., some bright young business-school graduate who had not won his footing in the organization was imported into the president's office as a "brain truster."

3. Executives failed to distinguish between personal and general staff functions. The "assistant to" was regarded as a "fair-haired boy" or "leg-man." His relations with the private secretary were not adjusted.

4. Executives failed to distinguish between long-range planning and current administration. "Assistants to" were used almost exclusively on new and special projects. They thus failed to relieve their chiefs of routine.

5. Executives attached too much importance to paperwork. They failed to allow "assistants to" to handle it for them. They had no appreciation of the doctrine of "completed staff work." They thus became desk-bound.

6. Such executives had no time to "make closer contact with their men." They thus closed a vicious circle. Because they would not leave "paper" and routine to their staff, they lost contact with their immediate subordinates. Because they had lost contact with their immediate subordinates, senior "line" officers would not accept the "representative" authority of general staff. Friction developed for which the general staff officer was blamed.

7. "Assistants to" were allowed, or even directed, to criticize and to report (sometimes overtly, sometimes covertly) on the work of their chief's immediate subordinates who were their seniors in status. Such action is bound to destroy their relations with such subordinates and hence their utility to their chief. Criticism is one of the chief's inalienable responsibilities.

8. Executives who had worked out a reasonable relation between their "assistants to" and their principal subordinates then went away for longish periods without nominating any senior officer of the corporation to "answer for" them in their absence. This placed the "assistants to" in a false position. They had either to act "for" their chief when everyone knew he was away, which upset his principal subordinates, or do nothing—which was apt to upset the chief on his return.

9. "Assistants to" were left in the position too long and felt that their prospects were uncertain. They should be picked men with an assured future in the organization. The training value of the position should be realized, and they should be informed that they will be moved back into the "line" within a fixed period (four or five years at the

most), usually at an executive level below that of their chief's direct subordinates.

10. The "assistant to" position was used as a "dumping ground" for "problem children," thus depreciating its dignity in the eyes of the rest of the organization and discouraging able young executives from accepting such appointments.

11. Possession of an "assistant to" had been allowed to become a status symbol. Where this occurs, especially with executives untrained in the use of general staff officers, it is bound to lead to the multiplication of jobs that have more title than utility and hence to uneconomic staffing.

5.7 DISTINCTION BETWEEN STAFF ASSISTANT AND STAFF SPECIALIST

The word "staff" is derived from the organization terminology of the military. In its broadest sense, it refers to the non-combatant elements of military organization, set apart from the *line* or fighting sector of the armed forces.

The staff was created when the commander-in-chief delegated the planning function to the "general staff," headed by the chief of staff. The general staff was to assist the commander-in-chief in the more effective exercise of his command through planning.

The functions of the chief of staff, as head of the general staff, are as follows: to plan operations, to consult with and advise the commander regarding field operations, to issue the commander's orders and promulgate supplementary orders to insure their proper execution, and to see that all orders are carried out.

Staff officers are of two kinds—staff assistants and staff specialists. The distinction between these two types of officers is described as follows.*

* This material has been adapted from some of the unpublished studies of Lt. Col. L. Urwick.

5.7.1 Staff assistants. The "general staff officers" in the United States Army ("staff officers" in the British Army) are extensions of the commander who aid him in carrying out orders, e.g. by interpreting his directives to subordinates. These men are almost invariably of lower rank than the commander's direct subordinates but are closer to the commander personally.

In business, the equivalent function is that of the staff assistant. He is the representative of his chief, acting purely in an advisory capacity with no personal authority. Even if, in his chief's absence, he makes decisions, they remain his chief's decisions.

5.7.2 Staff specialists. The "technical and administrative staff officers" in the United States Army ("specialized fighting troops and services" in the British Army) have an indirect "advisory" or "functional" authority in relation to the combat forces, the line. Their specialized responsibility is to prepare the plans, e.g. medical, legal, intelligence, technical. In business, the staff specialist is found in three major activities: (1) he advises operating departments, i.e., the "line," on his particular specialty; (2) his advice may apply to all parts of the business; (3) he has line authority in his own department. For example, the personnel director advises various departments on personnel procedures; his influence extends to all departments because the personnel function is all-pervasive; he exercises line authority in his own department.

5.7.3 The extent of the difference. There *is* some difference of opinion as to the extent of the difference between the two functions of "staff assistant" and "staff specialist." General Eisenhower told the author he thought the two functions were distinct but not diametrically opposed. Organization authorities such as Alvin Brown and Lt. Col. L. Urwick believe that the two functions are quite different. However, in discussing specific activities, it is not always easy to identify the functions definitely. Thus Lt. Col. Urwick, speaking of a personnel function in the Army,

states, "Personally, I do not regard the G-2 Personnel as a staff specialist. In the British Army he is called a Deputy Assistant Adjutant General and is definitely regarded as a staff assistant. But the whole question of the correct placing of personnel work is a most complex one." The answer depends on whether or not the personnel function is a delegated responsibility. If it is, then its head is a staff specialist and carries responsibilities. If it is not, then the person concerned with it is a staff assistant, and has no responsibilities inherent in his position.

6. NATURE OF FUNCTIONALIZATION: THE STAFF SPECIALIST

Line activities are those functions which follow one another as stages of major operations. These are sequential activities. One such activity is production. In addition, there are services common to line, which are grouped under major functions (hence "functionalization"—e.g., finance and personnel) and which are handled by staff specialists. These specialists are distinguished from line executives in that their authority is indirect, not direct; functional, not operating; and their responsibility specialized, not general.

6.1 ACTIVITIES OF THE STAFF SPECIALIST

The possible types of staff specialist activities vary greatly among companies. They may be summarized as follows: (1) staff advice, (2) operating service, and (3) direct command. (It should be noted that not all these activities are considered proper staff specialist functions in all companies. These are merely the staff activities found in the majority of companies surveyed.)

6.1.1 Staff advice. Staff specialists prepare plans, procedures, and standards, and provide counsel. These activities may be highly technical, and are often described as the exercise of "functional authority." They involve such steps as the following:

1. Gathering facts about managerial and technical problems of concern to the line.
2. Exchanging information on various company problems.
3. Drawing up policies, programs, plans, and procedures.
4. Discussing these with other staff specialists, staff assistants, and line executives, for advice and criticism.
5. Obtaining approval for the plan from all concerned.
6. Preparing written orders and making arrangements so that the plan is put into action.
7. Helping to install, explain, and interpret the plan, developing interest and enthusiasm, and advising line executives on overcoming difficulties.
8. Watching the operation of the plan and following up on progress.
9. Setting standards and establishing necessary controls, such as company standards, systems, and procedures, and implementing policies to assure that major company objectives and policies are carried out.
10. Measuring performance through reports and reviews.
11. Collecting and analyzing results.

It is clear, from this list of activities, that the work of the staff specialist is of a facilitating nature. The planning department exists, not so much to tell the foreman what to do, but to aid him in obtaining a more efficient flow of work by relieving him of the task of planning his activities. Authority to act is assigned solely to the line operator and should be commensurate with his responsibility for the results; if this authority were assigned to several individuals, it might be more difficult to place responsibility. Usually, only one man should give orders to a subordinate. The personnel department, therefore, should not possess the authority to direct the line department to hire the employees it sends; its function is to relieve the line men of the task of recruiting,

interviewing, and selecting new employees. Similarly, an inspector should in no case except an emergency have the authority to halt production, even though he can reject products. Finally, if the safety precautions prescribed by a safety engineer are violated by an operator, it is best to make the operator's superior responsible, not the safety engineer. The supervisor, being closest to the operator both physically and organizationally is in the best position to take the required disciplinary action.

Staff specialists are often available for advice and consultation to other staff specialists under the direct command of line officers. For example, the head office personnel department may always be available to aid the personnel director in one of the company's plants—e.g., in labor negotiations—at the request of the latter's line superior, usually the plant manager. The headquarters personnel staff may furnish plant personnel managers with up-to-date information on personnel developments in other parts of the company and in the field generally. Finally, such programs as executive development, job evaluation, and employment stabilization, which are highly specialized and require uniform application, may be outlined and offered to the line units by the headquarters staff specialists, who may also aid in their installation.

6.1.2 Operating services. A number of the staff specialists operate special service units to aid other activities. For example, the personnel staff specialist may have some of his subordinates run a cafeteria or be responsible for recreational facilities, a company magazine, safety work, and training. (The relationship of the personnel director to the cafeteria manager is one of direct command or "line.") Such separate service functions may include the handling of legal problems, public relations, taxes, office management, real estate and right-of-way, building design and construction, engineering, product acceptance, purchase and stores, traffic, and research, to cite examples of direct, centralized functions performed for the company as a whole. Other staff specialists, often at headquarters and concerned with such activities as finance, industrial relations, manufacturing, sales, and advertising, may perform certain direct services for the entire company, but act primarily as agencies responsible for performing "functional supervision" over the line.

The establishment of a service function is advantageous only when separating a unit is more economical than attaching it to another activity. A separate service function must involve full-time work for one man if it is to be worth while; otherwise, the activity can be assigned part-time to a regional line or staff man or be performed by headquarters. A separate service activity also raises the problem and additional expense of coordination. If it is decided to establish a service function, it is usually best to place it in the department that makes the most use of it—e.g., special statistical services might be placed in the accounting department.

6.1.3 Direct command. Under certain conditions, the staff specialist may issue direct orders, either in his own name or in that of his superior or chief executive. He may give orders to his immediate subordinates in his department—e.g., the director of industrial relations may issue requests or orders to the assistant director of industrial relations and to the director of personnel research. In certain exceptional cases, he may give directions to the line executives in order to (1) install new technical methods, such as job evaluation; (2) ensure uniformity—e.g., in the installation of a benefit plan; (3) speed up action without reducing the quality of a decision—e.g., hire a labor gang of unskilled workmen, more or less equal in ability; (4) improve quality of performance—e.g., participate in difficult labor negotiations that the line is unable to handle; (5) take necessary action in the absence of the immediate supervisor—e.g., a safety supervisor may order a man to leave a machine which is not operating properly and which may injure him.

6.2 AUTHORITY ENFORCEMENT BY THE STAFF

A serious organizational problem that may result from the creation of staff specialist functions is the assumption of command or line powers by the staff. It must be recognized that in actual practice staff specialists do at times exercise command powers over the line executives, in addition to those powers cited earlier, in order to get the results of their work accepted and thereby justify their continued activities. The following are some of the ways in which staff specialists require line executives to apply their suggestions. (It should be noted that such authority enforcements by the staff are widely opposed, not only by the line, but also by many organization specialists.)

6.2.1 Command through superior articulation. Staff men are generally articulate and skilled in persuading others to accept their ideas, while the line executive is often less vocal. A classic example drawn from another field is perhaps the success of Florence Nightingale in persuading the Army authorities to accept the nursing function during the Crimean War:

> It is easy to imagine the kind of disgust and alarm with which the sudden intrusion of a band of amateurs and females must have filled the minds of the ordinary officer and the ordinary military surgeon. They could not understand it; what had women to do with war?
>
> Miss Nightingale's position was, indeed, an official one, but it was hardly the easier for that. In the hospitals it was her duty to provide the services of herself and her nurses when they were asked for by the doctors, and not until then. At first some of the surgeons would have nothing to say to her, and, though she was welcomed by others, the majority were hostile and suspicious. But gradually she gained ground. Her good will could not be denied, and her capacity could not be disregarded. With consummate tact, with all the gentleness of supreme strength, she managed at last to impose her personality upon the susceptible, overwrought, discouraged, and helpless group of men in authority who surrounded her She stood firm; she was a rock in the angry ocean; with her alone was safety, comfort, life. And so it was that hope dawned at Scutari. The reign of chaos and old night began to dwindle; order came upon the scene, and common sense, and forethought, and decision, radiating out from the little room off the great gallery in the Barrack Hospital where, day and night, the Lady Superintendent was at her task. Progress might be slow, but it was sure. . . .
>
> On one occasion 27,000 shirts sent out at her instance by the Home Government, arrived, were landed, and were only waiting to be unpacked. But the official "Purveyor" intervened. He could not unpack them, he said, without a Board. Miss Nightingale pleaded in vain; the sick and wounded lay half-naked, shivering for want of clothing; and three weeks elapsed before the Board released the shirts. A little later, however, on a similar occasion, Miss Nightingale felt that she could assert her own authority. She ordered a Government consignment to be forcibly opened, while the miserable "Purveyor" stood by, wringing his hands in departmental agony.*

6.2.2 Command through technical competence. Since the staff specialist has technical skills and knowledge not possessed by the line department, his advice, like legal counsel, may have to be accepted. Also, renowned scientists and technicians in staff research departments may obtain acceptance of their ideas (or refusal of others' ideas) on the basis of their reputations alone. Finally, recommendations on such technical matters as staff training, quality control, and safety are difficult for the non-professional to dispute effectively and may, on that account, be accepted by the line, even though interference with operations sometimes results.

6.2.3 Command through status. Many staff specialists are considerably higher in the management hierarchy and in the salary scale than the executives they ad-

* Lytton Strachey, Eminent Victorians (New York: Harcourt, Brace and Company, Inc., 1948), pp. 141-143.

vise. They are able to obtain acceptance on that account as well as because of their technical competence. Staff specialists may be fortified by such titles as "director," "manager," "vice-president," and, occasionally, "member of the board."

Multiple influences on the line—that is, instructions from several sources rather than one—are found in many other fields. On the railroads, for example, the engineer is subordinate to the conductor, but he also obeys instructions of master mechanics, station agents, yard masters, and station masters.

The danger of staff command may be illustrated by an example drawn from military history. In World War I, German staff officers assumed field command. The fateful retreat of the German First Army behind the Marne was directed by an emissary of the Chief of Staff, who obviously lacked the line commander's first-hand knowledge of operations. Its surprised commander, who wanted to move forward and take Paris, was not even consulted! Some authorities believe that this false step lost the war for Germany. Other failures have resulted from the attempt of general staffs to engage in major planning for the line with the result that line men became automatons.

6.2.4 Command through sanctions. Line acceptance may be forced through the threat or use of sanctions. Staff sanctions may be so influential as to lead to demotion and removal of opponents, with the final result a hidden state of warfare between staff and line.

If a line executive does not agree with the staff proposals, the staff men may appeal to the chief of the staff function, who may, in turn, appeal first to the line executive's superior and then to the president, who could force the line to accept the staff counsel. As one company president explains this type of command: "In all cases, line supervision makes decisions. However, if there is a difference of opinion between line and staff on the lower levels, then the matter is referred to line and staff on the higher levels, with the line still being responsible for making the decision. In very rare cases, when no agreement can be reached on extremely important matters, I will make the decision myself. This would be the case only when high-ranking staff officials feel that a line decision has been made which will have extremely serious consequences for the company."

6.2.5 Command by default. Important problems may exist on which no line action has been taken—personnel problems, for example. This may be due to lack of time or interest on the part of the line. More seriously, it may be difficult for top line executives to arrive at agreement in open negotiations without "losing face." Consequently, the line executives may depend upon lower-ranking staff specialists and possibly their own staff assistants to reach agreement in informal discussions.

For example, a personnel director in one company with a number of plants believed it would be advantageous to have all plants begin to work out pension agreements with the union at the same time. The research director of the personnel department contacted the production planning staff specialists in the different plants and the staff assistants to the various plant managers, convinced them of the value of his superior's idea, ironed out difficulties with them, and got them to persuade their superiors. At the formal meeting of the plant managers, the personnel director, and manufacturing vice-president, the agreement was formally ratified. With this really united front, the union locals were approached. Such efforts on the part of younger staff and line executives to get agreement on technical problems are quite common in large corporations.

6.3 RECONCILING STAFF SPECIALISTS AND LINE OPERATORS

The following are a number of general proposals for integrating the activities of staff and line executives and for improving their relations. These may best be examined in terms of the successive stages of reconciliation in-

volved in solving a typical staff-line relationship problem.

6.3.1 Integrating staff and line activities. 1. *Familiarity with line operations.* It is desirable that the staff specialist have some experience in the line so that he may know its problems and understand the kind of organizational relationships necessary to its successful operation. A number of companies make line experience a pre-requisite for staff work. Where such an arrangement is not possible, an apprenticeship as "assistant to" a line executive might be arranged. In most instances, it will be desirable for the staff specialist to spend some time in getting acquainted with the line executives and in finding out their problems before making any recommendations.

2. *Persuasion rather than command.* The staff specialist should get line executives to accept his ideas by using argument and negotiation rather than by forcing his authority upon them. His advice, therefore, must not only be sound; it must be tactfully presented as well. This requires much diplomacy on the part of the staff specialist. Suggestions should be integrated with line operations and with other staff proposals and should be carefully considered and tested. Informal checks might be made with the line before the ideas are formally presented to assure that they are practical and thus forestall any possible resentments. The ideas should be presented at the right time and in language understandable to the operators. There should be scope for amendments. Finally, the staff specialist's proposal should not be introduced until it is approved in its final form by the joint superior of the staff specialist and the line executives affected (many companies insist on the agreement of all line executives). Although credit for success often goes to the operators, staff specialists must remember that success is often as much dependent on them as upon the man on the line. Exceptions to the rule of staff consultation and coordination with the line should be made only under extenuating circumstances.

3. *Use of informal approach.* Lt. Col. Urwick advises us from his long experience:

> Officially speaking, authority must be exercised only through the line superior —that is, with his approval and agreement. This does not mean, however, that all action must climb wearily up one chain of command, across the top, and down the other chain. Once a specialist has won the confidence of a line executive and has no intention of infringing upon his authority over his subordinates, he can do 90 per cent of his work direct, provided he is meticulous in observing two precautions: (1) He should always have the common courtesy to inform a line executive of any action he has taken affecting any of his subordinates. (2) If there is the least chance of disagreement about any action, he should consult the line superior first.
>
> It might be thought that this careful observance of "official channels," with all the resulting paper work, must necessarily slow down business. But this conclusion rests on a misunderstanding of what this paper work is for. It is "for the record," a safeguard in case personal relations break down, not a primary means of getting work done. All the real work of the world in good organizations is done by men who trust each other. They agree on decisions on the telephone, using first names. Then they merely tell their secretaries to "file the confirmation when it comes through." If there is the least chance of misunderstanding or disagreement they try to meet each other face to face; if you can't see the other fellow's eyes, you can't really tell "what's biting him."

4. *Resolving disagreements.* If the line should disagree with the staff specialist, the latter should continue his attempts to obtain agreement rather than enforce his ideas by assuming authority himself or exercising it through others. Though staff promotion may gain verbal acceptance of a program, its successful execution can be sabotaged in many ways.

Should an accepted policy be violated, the staff specialist should call this to the attention of the line executives concerned. If no agreement is reached, the matter might be carried to the head of

the specialist function or to the joint superior of the two parties. In extreme cases, the dispute may be carried still higher up—eventually to the president or the board. The process of carrying out a staff policy (or gaining its acceptance) through persuasion, technical competence, or appeal to a joint superior is a broadening of functional authority requiring very good judgment on the part of the staff specialists.

Long friendship and, if necessary, a more tolerant interpretation of the rules can usually aid in settling disputes. If that is not possible, a written (or oral) statement of the recommendations not followed by the line may be given by the staff specialist to his superior and possibly to the joint superior. This would place on record the staff specialist's position and prevent him from being blamed for failure to recognize shortcomings. It is usually best to leave matters there rather than arouse animosity. However, if the disagreement between staff and line may hinder the staff's work in the future, the matter may be carried further.

Occasionally, the problem of disagreement is solved by giving the staff specialists "concurrent authority," requiring the line executives to obtain staff agreement to carry out a proposed action. However, the line would still remain free to reject staff directions.

6.4 RECONCILING STAFF AND LINE IN LARGE COMPANIES

In the large company, a number of special procedures may be required to reconcile staff and line executives. These procedures are divided into those which concern lower-ranking line executives and those which deal with higher-ranking line executives.

6.4.1 Reconciling lower-ranking staff and line executives. The first type of reconciliation concerns chiefly the relationship of supervisors (assistant foremen, foremen and general foremen, and possibly superintendents) to the staff specialists. The procedures involved in this relationship should be kept relatively simple so that they can be easily understood and followed. Outstanding for its treatment of the line-staff relationship for training at the lower supervisory levels is the *Leader's Guide* of the Ford Motor Company. It should be remembered that the following procedures apply to a very large company and therefore may not be identical to those required by other, smaller concerns.

The following principles, which should help govern the relationship between line management and the staff, are outlined to manufacturing supervisors at special training sessions. Printed summaries are later distributed to supervisors participating in the training program:

1. *You Have Only One Boss.* Note that you have only one boss on the line. There is only one spot in this whole organization chart from which you receive your assignment of responsibility and from which you receive a delegation of authority. As a subordinate, recognize only one immediate supervisor.

2. *As a Supervisor, Give Equal Support to Equal Subordinates and Only to Your Subordinates.* You are the supervisor on the line to the subordinates below you. When it is necessary for you to transmit orders or policy statements, or give instructions and directions, you should do so only to your immediate subordinates—that is, to those on the line just below you. As a boss, you may have several subordinates. You may find it necessary to define the assignment of responsibility and the delegation of authority to each man individually, according to the merits and abilities of each.

3. *Directions Flow Down the Line, Reports Flow Up the Line.* Directions, orders, instructions, etc., flow *down* the line. It is necessary for each supervisor to make interpretations to his subordinates. These should be stated clearly and understood by both the supervisor and subordinate. Reports flow *up* the line. Recommendations, suggestions, and ideas are often submitted by a subordinate to his supervisor. Many of these will be of interest to the supervisor only. On the other hand, it may be advisable for him to make further report on certain

matters to his own supervisor on the line above him. Just how much he should keep and how much he should pass on up the line calls for the exercise of discretion and good judgment on *his* part.

4. *Keep the Line Open.* We should also keep the line open. As a supervisor, your subordinate may have submitted to you a recommendation on which you have taken no action. Your subordinate may feel that you have not used good judgment in doing this. He may feel that it is important enough to warrant passing up the line for further consideration. If he discusses the problem with you, you may openly admit that, although you see certain difficulties that may prevent adoption of his recommendation, you have no objection if your subordinate goes above you on the line and presents his recommendation direct. Not only this, but you may go so far as to arrange for your subordinate to present his proposal to your supervisor with or without your presence and participation (some companies prefer both men to go together). This does not violate the principle to keep in line, because you have given your consent. If the proposal has merit, see to it that your subordinate gets the credit. If it has no merit, you will be given credit by your supervisor for having foreseen the difficulties that were involved. (In addition to keeping the line open, a line supervisor should serve as a buffer for his immediate superior to prevent obviously unnecessary or wasteful demands on the latter's time.)

5. *Keep the Line Advised.* Sometimes a break occurs in the line. It may be that one of your subordinates is at home, sick; or if you have pulled him off his regular job temporarily for a special assignment, it may be that you do not wish to have him disturbed. In transmitting directions down the line, it may be necessary for you to skip him and give those directions to the person next on the line below him.

Similarly, if your supervisor cannot be reached or is out of town, and you must report on some matter, it may be necessary for you to skip him and make the report to the supervisor next on the line above him.

Whenever a line supervisor skips an echelon of supervision above him in passing on information or below him in giving instructions, he should advise the supervisor concerned as soon as practicable.

6. *Associates Support Each Other.* Associates working together should support each other. If we support the associates we work with, they, in turn, will tend to support us. We shall get each job done more quickly and at the same time pave the way for close cooperation in future jobs.

7. *An Associate on the Line Has No Authority over an Associate on the Staff, and Vice Versa.* Ordinarily the staff has no authority to command or direct that certain action be taken on the line. Their suggestions may or may not be accepted by the line.

If a staff recommendation is made to a member of management on the line, and it is not accepted, there is a possibility that later the same recommendation may be accepted by your supervisor on the line. In this case, he may transmit the decision as a directive down the line to you. You as subordinate will be responsible for carrying out the directives of your supervisor. Responsibility for acceptance is his, not yours.

If you feel that there are valid reasons why the proposal should not have been accepted, you still have the privilege of discussing the matter with your supervisor. But, until he has changed his decision, you are bound by your line responsibility to carry out that directive as it was originally given to you.

It should be noted that at some large companies, staff personnel may be delegated specific authority to act in certain matters on behalf of line management, and in such cases the staff, as representatives of line management, may exercise "functional" supervision over the line. In any large, complex operation, such flexible lines of demarcation between line and staff are mandatory if line management is to be relieved of part of the burden of handling details.

6.4.2 Reconciling higher-ranking staff and line executives. In the large company, the relationship between the higher-ranking staff and line executives within a branch, as well as their relationship with staff headquarters, constitutes a serious problem.

This problem may be most clearly studied when a company shifts from

direct supervision of headquarters staff over the branch or regional staff to supervision by a newly appointed regional general manager. In the following example, the regional staff men, who had been directly responsible to the headquarters staff men, became responsible to the regional general manager after decentralization took place, retaining an advisory relationship with their former headquarters staff. The regional departmental managers' reaction to the change varied all the way from an attitude of complete severance of connections with headquarters ("I don't know what headquarters will do now that I do all the work"; "Maybe they'll have to play golf to keep busy now"; etc.) to a conviction that no change had taken place in the relationships ("I have a continuous pipe line to headquarters"; "Whenever I need any help I call headquarters"; "There is going to be no change in my job"). A minority thought the regional general manager "would continue as coordinator," "was too busy," "did not have experience and knowledge of headquarters," "could be sold easily," "was just a formality."

The general attitude that prevailed among the regional departmental managers was one of perplexity and apprehension regarding the staff-line relationships. For the most part, they were concerned about personnel increases, specific operating decisions, and their own promotions. Who would have the major say—their former headquarters staff superior or their new superior, the regional general manager?

In the large company with a number of plants, a basic problem in line-staff relationships is whether the staff specialists are to be independent of the plant operating executives or responsible to them. Independence would mean that headquarters staff specialists would advise line operators at the plants directly from headquarters (and possibly also through subordinates in the plants). This procedure has the advantage of saving the expense of duplicate staff units in the plants and avoiding the dangers of parasitic growth at every level of command. It would make possible the full advantages of large-scale specialization. It would encourage uniformity of policies and procedures as well as coordination from the center. Auditing control in financial matters (e.g., accounting methods) might be more reliable if the plant financial specialists report directly to headquarters.

However, the centralization of staff specialists might also entail serious disadvantages. For example, it might undermine effective leadership at the operating unit (the plant). If a plant manager is subject to a variety of regulations, which may often be too insensitive and too rigid to be applicable to local conditions, his initiative and leadership may suffer, especially if headquarters is out of touch with the "feel" of the local plant situation. Serious conflicts may result between the staff specialists, who may have to act strictly to enforce headquarters thinking, and the plant manager, who may wish staff specialists to have merely an advisory relationship.

One way of overcoming this difficulty might be to set up the operational unit as a separate entity, as far as possible. The plant manager would receive all the decision-making powers necessary for the most successful possible day-to-day operations, and obtain from staff specialists any aid necessary to that end. Should the suggestions of local staff specialists, who are responsible to the plant manager, prove more applicable to a particular situation than advice or action from headquarters staff specialists, the former would be adopted. For example, though concentration of toolmaking or purchasing at headquarters may result in considerable economies and advantages, these may be offset by the frustrations and delays at the local plant level.

For purposes of clarification, a staff-line relationship is outlined in Fig. 1.6. This has been adapted from a suggestion by Sir Charles Renold, Chairman of the British Institute of Management, and Chairman of the Renold and Coventry Chain Co., Ltd. In this chart, the activities of a large corporation are

broken down into manageable areas. A large number of separate plants are held together by headquarters, which exercises a kind of federal authority. Here the top staff specialists of the various functions assign general spheres of activity, help to provide financial support, make long-range and highly specialized plans, review results, and are available for advice to the second tier, the regional or group level. The regional level again provides all the specialist services necessary to operate the region as a rational and, as far as possible, self-contained unit. The third tier is the division, which consists of several plants and again is operated on a self-contained basis. The fourth level, the plant, has its own set of plant specialists directly responsible to the plant manager, who, at the same time, accept advice from the staff specialists of the division. The plant is still subject to overriding uniformities in such matters as personnel policy, accounting, operating and capital budgets, and other top management functions (discussed below), but it operates with considerable freedom. Its size may vary from a few hundred to a few thousand employees.

Such a rational operating unit in industry may, in some ways, be compared to a single ship in the navy, as has been suggested by Sir Charles Renold. The ship is a self-contained unit, and all its major relationships are handled by the captain, even though he may be subject to certain overriding influences by larger units—the squadron, the fleet, and the commander-in-chief of all the fleets. The relationships between such different levels or units within a company may be improved by such techniques as the following:

1. Physical separation of headquarters and the regions in order to avoid an excessive degree of mutual interference.

2. The utilization of a policy manual to acquaint line organization with the functions, relations, and use of staff departments.

3. Regular interchange of information on the activities of regional departments and headquarters, through bulletins, reports, meetings, interchange of personnel.

4. The appointment of a top official to act as part-time intermediary and impartial umpire between headquarters and plant in case of disagreement.

It is clearly impossible to lay down hard-and-fast rules for staff specialists' relationships. In general, however, the maximum possible scope for personal initiative within the organizational framework, consistent with the lowest relative costs, would seem to be desirable.

7. COMMITTEE WORK

Group action is increasingly characteristic of American management, especially in the larger corporations. Of 150 multi-unit-companies surveyed by the author, 110 reported that they have one or more committees meeting regularly. More than half of the companies studied have a general management committee to discuss problems of over-all company significance. Sometimes this general committee consists of full-time working directors. In most cases it is composed of working directors of the board and the heads of the major functions of the business. Meetings are held at regular intervals and committee duties are only part-time obligations.

In addition to the general management committees, many companies have functional committees with limited authority over a particular aspect of the business, such as production, sales, or personnel. In addition, frequent informal group meetings are held.

The major requirements for success of committee operation may be summarized as follows: (1) Work of committees should justify their costs. (2) The principles of effective group action should be applied. (3) Committee mechanics should be arranged so that meetings will not be hampered by procedural difficulties. (4) Only subjects that can be handled better by groups than by individuals should be selected for committee discussion.

7.1 JUSTIFICATION FOR SETTING UP COMMITTEE

The aim of committee work is to get a more comprehensive view of a given problem than can be obtained from any single member. If one member of the group gets his particular view accepted by dominating the rest, he might just as well have made that decision outside the committee meeting. Similarly, a compromise can often be reached without a committee meeting. If we accept profit maximization as the company's over-all objective, then the purpose of a committee meeting is to obtain a result that contributes more to company revenue than the expenses it entails. This is hard to measure. However, positive committee contributions to company revenue may include:

1. Problem-solving. Many problems of management are complex and affect different functions; often their impact is company-wide. Decisions must be made on questions to which there is no clear-cut answer, but where feeling, "instinct," and personal opinion play a vital part. Some decisions require the counsel of experts in various fields. Since the view of each is somewhat different, the synthesis of their opinions should be better than those of any one person involved. Moreover, long-run considerations are more likely to be emphasized in a group decision. Other problems require the consultation of two or more departments for proper balance and an over-all view, e.g., determining levels of output on the basis of probable sales. Individuals are safeguarded against the danger of thinking too long alone. The stimulation of participation may lead to better ideas and their more wholehearted acceptance.

2. Coordination of related functions. Committee work makes an important contribution when its members meet in order to determine what parts they shall take in a pre-determined course of action in order to avoid overlapping or working at cross purposes. This function of the committee is especially important when there is no other means of coordination. The committee also may serve as a means of communication among the representatives of large groups.

3. More complete acceptance of a decision already reached. Making a decision does not, of course, ensure that it will be carried out effectively. If those affected by the decision disagree with it or are aggrieved because they were not consulted, they may oppose its execution in many ways. The committee offers an opportunity to air arguments against a proposed action and clarify its advantages.

4. Training. Participation in committee meetings may be used to help to train younger executives and give top management a chance to observe them in action.

Against these possible contributions to company revenue must be set the following gross costs (which should be compared to the revenue and cost of handling the problem through individuals):

1. The direct cost of the committee, such as the time of the committee members in preparing for the meeting and at the meeting itself, the expenses of the committee staff and secretary, the cost of office space and clerical work, the time spent traveling to and from meetings (important in large companies where executives may have to travel some distance).

2. Additional expense may arise from committee work because of the lack of responsibility for results on the part of committee members. Since a group of persons cannot be held responsible in the same sense as an individual, decisions may not be properly carried out.

Neither the committee as a whole nor any individual member can be criticized effectively. If the group takes action that is not well received, no individual can be blamed. Unpleasant questions or problems can easily be shelved. Committees also are expensive, because they tend to be bad employers. The individual subordinate finds it hard to know whom and how to please. If he does take action, some member of the committee may disagree with it; if he does not, he may be charged with negligence. This complaint, familiar among employees of club committees, was given prominence when Car-

roll L. Wilson resigned in July, 1950, as general manager to the Chairman of the Atomic Energy Commission, warning that the five-member Atomic Energy Commission was drifting toward a policy of "management by committee": "I have serious apprehension that the ultimate projection of this trend will result in a cumbersome, slow-moving administrative machine which is incapable of giving the country the kind of direction needed to maintain and increase our leadership in the atomic field." More recently, a scientist charged that the members of the A.E.C. Advisory Committee were acting like the passengers in an automobile where each had control of the brakes; no progress could be made until all the advisers agreed.

If these criteria for cost and benefit appear too complicated and inaccurate, it might be possible to estimate regularly for each committee the total number of man-hours involved in a year of meetings, as follows:

1. Multiply the number of meetings per year by the average number of hours per meeting and the average number of executives attending a meeting.
2. Add the number of hours spent by the secretary and his staff in planning meetings, distributing agenda, writing minutes and recommendations, etc.
3 Multiply the total man-hours by an average hourly salary cost figure.
4. Estimates might be made for the past and the coming 12 months.
5. List past accomplishments and estimate their possible monetary value.
6. Attempt to determine how the functions assigned to the committee would be carried out if the committee were abandoned.

The study should conclude with a recommendation as to the committee's future.

The committee may meet merely to satisfy the chairman's ego. Free discussion may be curtailed for fear of offending others. The committee may operate as a rubber-stamp for an individual or a clique. Agreements may be made for agreement's sake, as a result of horse-trading or log-rolling, entailing undesirable compromises. Certain individuals may have blind spots or may be overly articulate, may fail to express themselves adequately, or may fail to carry their share of the work and responsibility entailed. Committee decisions may be slow; they may not be carried out or may be inadequately followed up. The tactics of "agreement" may be bulldozing, withholding facts, maneuvering a prior majority, falsification of data, "guiding" agreement, intrigue, sabotage, or giving only the semblance of democracy by letting everyone talk and then forcing agreement to a decision reached before the meeting began. Individual contributions to discussion may be irrelevant or designed only to impress a superior. The committee may exceed its authority or, at the other extreme, may be lax in exercising it.

7.2 APPLYING PRINCIPLES OF GROUP EFFECTIVENESS

It is an erroneous assumption that anyone can be a good committee member. The proper role in a group is a difficult art, mastered by relatively few. Although almost everyone spends much of his working (and social) life with formal and informal groups, only rarely is there systematic training for effective group behavior at any stage of a person's career. One of the few companies that have supplied informal training in committee management is the Standard Oil Company of New Jersey. In general, however, knowledge of and training in committee work have been acquired largely through experience, which has often been costly.

Successful committee action requires selection of members who are able to express themselves in the presence of a group. It is surprising how many otherwise able individuals find themselves completely tongue-tied when confronted by a small audience. The objectives and limitations of the group must be considered. The committee requires only those contributions that will advance group thinking (without necessarily ad-

vancing the individual). Conflicts must be resolved by integration rather than by domination and compromise. Group work calls for emphasis on concrete considerations and practical actions rather than undue preoccupation with theoretical matters.

Some of the elements of effective group participation have been systematically studied in the course of the human relations research sponsored by the United States Navy.* Some of the hypotheses and findings (as a rule based on small samples) may be adaptable to management committee work:

Productivity of the committee is said to vary with:

1. The urgency of the problem (pressure to show results may lead to concentrated and economical committee work or to impressive accomplishments on paper only).
2. Power to make decisions. (Delegation of responsibility may move participants to exercise it, but collective responsibility to make decisions does not necessarily mean that they will be made or that, if made, they will be superior to individual decisions.)
3. Ease of communication, degree of mutual understanding and freedom to participate. Freedom of expression is vital in getting results. (However, if consideration is not shown to the feelings of others, it may be a mixed blessing.)
4. Orderly treatment of problems. (However, treatment may be too orderly with consequent loss of flexibility.)
5. Intelligence and originality on the part of individual group members.

The extent of agreement among the members of the group is said to be greater:

1. The stronger the attraction among individual participants in the group;
2. The more personal friendship there is among members of the group, for opinions can be more easily changed;
3. The greater the uniformity of the group;
4. The fewer dissenters present;
5. The more readily each reacts to another's action;
6. The greater the cooperation and the less the competition.

There is little disagreement with these propositions. Most of them are self-evident, though it is valuable to have had them tested. The point that needs to be questioned is the desirability of agreement for its own sake—for if everyone agrees, what contribution does the meeting make? There is no advantage to the company or to the participants from meetings that merely satisfy the ego of the top executive present. Sessions held to bring about agreement may have some value. But the real test of the committee is its effect on company revenue. Its contribution to "morale" (whatever this vague term actually means) may be important, especially in relations between the management and other parties in the enterprise, such as labor. But, over-all, the economic test would seem the most important one.

7.3 COMMITTEE MECHANICS AND ELIMINATION OF PROCEDURAL DIFFICULTIES

7.3.1 Definition of function and scope. The first step in successful committee action is definition of the function and the scope of the committee.

7.3.2 The size of the committee. Next, the proper size of the committee needs to be determined. With less than five or six members, it may not realize the advantages of group work. On the other hand, if there are more than 15 or 16 members, the group becomes a crowd. Generally speaking, the larger the committee, the greater the areas of disagreement; and the harder it is to reach a decision, the greater the expenses involved. On the other hand, a larger committee is usually a more representative group, draws upon broader and more diversified experience, and makes it possible to reach more people. By bringing in experts where needed and through the use of sub-committees, it may be possible to obtain the advantages of a large group without making the group unwieldy. The specific size of

* Harold Guetzkow, ed., *Groups, Leadership and Men* (Pittsburgh: Carnegie Institute of Technology, 1951).

the committee depends on many factors: the type of problems to be discussed, the competence of the participants, the homogeneity of the group, the degree of integration of its members, the nature of the participation required, the amount of face-to-face contact that has existed in the past, the clashes of interests that may be expected.

7.3.3 The chairman. Perhaps the most important aspect of the mechanics of committee work is the choice of the proper chairman. The man who presides exercises great influence. His age, experience, or status in the company often enables him to make or break the committee, even though in theory he may be merely "the first among equals." This strength of position also imposes grave responsibilities—he must avoid imposing his own opinion or relinquishing his powers to other members. As an example of an "ideal type" of chairman, the scientist Carl Alsberg may be cited:*

> He was an intermediary, marshaling expert advice and cooperation from whatever department they were needed. When he sought information or assistance, he was scrupulously careful to drop in on his informant and never to request anyone, even his juniors, to come to him. Alsberg never tried to make an impression. His simplicity was disarming. The delightful informality of the man, the total absence of selfishness, the complete reasonableness, and the understanding of the other person's point of view instilled confidence. The sincerity with which he could place the welfare of an institution, of science, or of any worth-while endeavor above minor considerations inspired cooperation. "No scheme of cooperation can work better than the cooperators are willing to permit," he observed. The task of creating the will often fell to him. Yet in these dealings with others there was never a trace of personal ambition, or insincerity, or a desire to wield power, but only an eminent reasonableness in behalf of ends to which he had a fair-minded attachment.
>
> In meetings he was informal and casual but adroit. He would at times appear to ramble far from the subject, in order to bring out forcefully and effectively in the end some relevant point He knew how to intercede. By taking a recalcitrant committeeman's side and stating for him a generous version of his views, and then by showing the basis on which agreement might be reached, Alsberg could often win the recalcitrant over, maintain harmony in the group, and earn the gratitude of his confrères
>
> Committees were to Alsberg more than a way of reaching group decisions. They were a medium of communication, helpful if not essential to understanding and cooperation in any large organization.

7.3.4 The secretary. The decisions of a group of executives usually are recorded and communicated to others in writing. Oral communications may be misunderstood and may not reach all those concerned. In theory, the secretary has no influence on the committee's deliberations. His task is merely to record what has occurred in the meetings. But that task involves a selective process that imparts much power. The secretary also may influence the committee if he is asked to prepare data and investigate material for the committee's consideration or to formulate the agenda. His power is enhanced when the chairmanship is rotated frequently. As in the case of the chairman, an appreciable difference between the secretary's nominal and actual authority may cause jealousy and dissension.

7.3.5 Getting action. To insure accomplishment of desired results, committee members should give some advance thought to the deliberations. In many committees the problems to be considered are broken down into manageable portions and analyzed well in advance; relevant documents and reports are sent to participants several days before the meeting for study. During the meeting, the basic problems are broken down into their major components and all points

* The quotations were taken from *Robert D. Calkins*, "University Professor and Administrator," in Carl Alsberg, *Scientist at Large*, edited by Joseph S. Davis, Stanford: Stanford University Press, 1948, pp. 76-78, 94-95, 99-100.

of view are presented. Committee meetings may end with a summary of proceedings to unify the main points of the discussion. Definite action may be decided on and assigned to special committees or subcommittees. Provision is also made for follow-up on these committees' activities. Many who are experienced in committee work are opposed to formal voting because it tends to split the group. They prefer adoption of a solution corresponding to the "sense of the meeting"—i.e., the consensus of the group—if this can be arrived at. However, votes are useful in establishing a firm decision for the record. Voting has been used successfully by a number of committees that operate informally. The division of the vote is not communicated outside the committee.

7.3.6 Scheduling the meetings. Many feel that committee meetings should be bunched together to leave plenty of uninterrupted time for work. For example, General Motors groups all committee meetings into two periods each month, with two meetings on consecutive days in New York and two or four consecutive days in Detroit.

7.4 SELECTING SUBJECTS FOR COMMITTEE DISCUSSION

For every group action leading to a decision there is the alternative of individual action The basic issue is whether group decision-making (through a formally established committee or conference or through informal meetings) is superior to individual action.

To make the comparisons necessary, management activities may be broken down into such categories as planning, control, and organization, and the respective merits of individual and group action for each management activity analyzed.

The author attempted to find out, through interviews with executives and inspection of records in a score of large companies (not necessarily representative) the relative merits of individual and group action. A rough estimate was made of the proportion in which different management activities: (a) can be exercised effectively by committee (group) action; (b) can be exercised effectively by committee action, but more effectively by individual action; (c) can be exercised by individual action, though supplementation by committee action may be helpful; (d) require individual action because committee action is ineffective.

To summarize these rather rough breakdowns of the sample of 20 multiunit companies, committee action seems to be definitely superior in settling questions that may give rise to jurisdictional disputes within the company; individual action seems to be superior in providing leadership, in organization structuring, in execution, and in decision-making. Committee action is slightly superior in communication, but slightly inferior in planning, formulating objectives, and administration. Committee action is approximately equal to individual action in control, technical innovation, and advisory activities.

8. DECENTRALIZATION

The acid test of managerial decentralization is the degree to which executives participate in decision-making. Or it may be put in this way: How far has the company moved away from one-man control of all major decisions? Traditionally, many of the early economists and business writers described the average enterprise of their day as a one-man business, run by the owner-manager. Thus the great economist Alfred Marshall spoke of the employer as "himself exercising a general control over everything and preserving order and unity in the main plan of the business." And this description seems to have fitted the typical nineteenth-century business decision-making rather accurately. Since then, of course, the locus of decision-making has moved from the owner-manager to the professional manager. It is no longer true that "where the risk lies there also lies the control." As a matter of general practice, provision is frequently made, either by statute or charter, for delegat-

ing the direction of the company from the owners or stockholders to a specially selected board of management, commonly known as the board of directors, designed to act on behalf of the owner.

In addition to the delegated framework for the exercise of the powers conferred upon the board of directors, there are the statutory corporation law, the charter and certificate of incorporation, as well as the by-laws drafted and accepted by the stockholders. These are the articles which govern the conduct of the business in a broad sense. The board of directors usually has wide grants of power, including the power to amend or enact the by-laws.

The board of directors in turn usually delegates a major part of its powers to the company's chief executive, who is the president or—less frequently—chairman of the board of directors, or a combination of the two. The chief executive possesses very great powers, as a rule. One important question in decentralization, therefore, is this: Which powers does the chief executive reserve for himself and which does he delegate to his subordinates? The actual degree to which major decisions are delegated in a particular company may, for example, be determined by use of a questionnaire.

8.1 DECENTRALIZATION AS A CRITERION OF ORGANIZATION

In and of itself, managerial decentralization is neither desirable nor undesirable. We must apply certain criteria in order to evaluate it. One such criterion is economic efficiency: At what point in the management hierarchy and by what individual is a particular decision made most efficiently? Is a particular function exercised or a service performed more cheaply if it is "centralized" or "decentralized"? It is impossible to say in general that either centralization or decentralization is more efficient. It depends on the type of decision involved. The more costly a mistaken decision, the higher up it should be decided (provided the higher-ups make fewer mistakes in the matter under question). Obviously, the price to be paid for a major raw material purchase would be better decided by top management than by a foreman. On the other hand, the less costly a mistaken decision, and the greater the need for a speedy decision, on the spot, the nearer to the source of origin it should be made.

It should also be borne in mind that the same degree of decentralization need not apply to men doing the same work or having similar status. For example, in a textile plant, certain decisions regarding the quality of finished goods can be made at the point of operation, since the disadvantages of a wrong decision to the company's reputation might not be sufficiently important to warrant control at a higher point in management. However, in quality control of pharmaceuticals, an error may be of such consequence to the company's reputation that every safeguard must be imposed to prevent a wrong decision. In such a situation, the quality control director should probably report to the president or at least to a senior officer.

Finally, the same degree of decision-making power may be given to two men doing the same job and the economic result may be entirely different. Different personalities may have completely dissimilar abilities to exercise judgment when on their own. This will be obvious to any reader who considers the decision-making ability of those about him—how some cannot be trusted to do anything right unless they check each time before they make a move, how others unfailingly come up with the right answers by themselves and would merely be hamstrung if they were more closely controlled.

Just as decentralization is not necessarily good or bad from an economic point of view, the same holds true from a non-economic standpoint. It is widely believed that even if decentralization cannot be justified on economic grounds, it is worth while because it is "democratic." But the term "democracy" is a concept of political science. It is based on the premise of man's equality. In business,

men are not equal in every sense—for, obviously, their salaries, status, and power differ. Therefore, it would seem inappropriate to apply this term to business relationships. Nor is decentralization necessarily advisable because it involves participation. Participation may be desirable, but it may not be practicable under many circumstances. Moreover, some executives do not wish to assume the responsibilities that participation entails; they may prefer an authoritarian relationship. And even where executives desire participation, extra expenses entailed for additional staff and the slowing down of decision-making may not be offset by the benefits to be derived.

Knowledge of the locus of decision-making within the company at best provides only a partial answer to the nature of its decision-making. To have a more complete picture, one must also know how decision-making is divided between owners and management hired by the owners, the impact of outside forces (government, consumers, financial interests, labor unions) on the company's decisions, and the relative emphasis given decisions involving short-run and long-run questions.

8.2 FACTORS AFFECTING THE DECISION TO DECENTRALIZE

Since decentralization is not of itself a criterion of a good organization, on either economic or non-economic grounds, we must apply certain criteria in order to determine whether, and to what degree, decentralization is advisable in any given situation.

In this connection the following factors may serve as tools of analysis: (1) size of the company, (2) nature of the company's business, (3) economic trends, (4) political trends, (5) management philosophy, (6) personality, and (7) nature of the individual management functions.

The basic standard underlying this analysis will be profitability—i.e., to what extent will delegation of decision-making lead to a reduction in unit costs by lowering salary expense on given decisions? To what extent can profits be increased through improved decision-making—either directly or indirectly?

8.2.1 Size. The cost of making decisions generally tends to be higher the farther away they are made from the point at which the problem arises. Moreover, the decision itself may be less satisfactory. The larger the size of the firm, the more numerous the decisions that will have to be made, the longer it will take to make them at the top, where they accumulate. Similarly, the greater the time and the physical distance involved, the more extensive and complex will be the process of communicating accurately the decision to everyone concerned. And, finally, the larger the size of the company, the harder it will be to have the decision carried out as effectively and expeditiously as might be desired. To cite one instance, at a large company a study of the evolution of several policies showed how difficult it was to arrive at a decision. It was found that decisions made at the top often reached the foremen in a very garbled form and their application was quite different from what was originally intended.

The big firm may well be a series of wheels within wheels, an elaborate hierarchy in which every decision requires the consulting of this man, the referring to that man, the permission of a third, the agreement of a fourth, and the informing of a fifth—so that decisions may become endlessly delayed. Where decisions must be reached frequently and quickly, such an organization, unless despotically controlled, may find itself paralyzed—and, if it is in fact a despotism, much of the benefit of specialist services and advice may be lost. The small firm, on the other hand, may be more often and more successfully despotic. The decisions are those, as a rule, of a single individual, made quickly and decisively.

To illustrate, contrast the process of decision-making in a small and a large firm. An oil company, we shall assume, is considering whether to undertake the heavy expenses of drilling a series of oil wells. The opinions of the departments

affected are sampled. The exploration department may be convinced that it will be a highly profitable venture. The production department has estimated the cost and has determined the probable yield of the investment. The treasurer has the funds, but may be doubtful about the returns as compared with those obtainable through other uses of the funds. The sales department may not be certain about the possibilities of selling the additional refined products profitably. The personnel director may not be sure about the availability of the necessary skilled personnel. In some way or other, the chief executive and the board of directors will have to weigh these different considerations against one another and reach a decision. How much simpler is the decision where the chief executive is just a "wild-catter." He decides by "feel," hunch, and hearsay, superimposed on highly specialized technical knowledge.

A reduction in the size of the decision-making unit, by splitting an existing large unit into several units, each smaller, and delegating to each decision-making powers, may bring about considerable increases in efficiency, in such ways as the following:

1. Executives will be nearer to the point of decision-making: Delays of decisions, caused by the necessity of checking with headquarters and/or top officials, are reduced by managerial decentralization. Since people on the spot usually know more about the factors involved in the decisions than those further removed (by physical distance and authority), and since speedy decisions may often be essential (competitors may move in otherwise), such a delegation of decision-making is advantageous. It also saves the considerable expenditure of time and money involved in communication and consultation before the decision is made. These savings may increase as the geographical dispersion and the volume of company activities increase. (A notable example of a chief executive who believed in the delegation of decision-making was Samuel Zemurray, former President of the United Fruit Co., who made his division managers' autonomy real by his stock message in reply to questions: "You're there, we're here.")

2. Efficiency may be increased because there may be a better utilization of the time and availability of executives, some of whom may formerly have shunned responsibility as much as possible, automatically "going to headquarters" as soon as any problem came up.

3. The quality of decisions is likely to improve as their magnitude and complexity are reduced, and as major executives are relieved of possible overwork. The top men will be able to concentrate on the most important decisions. As General Eisenhower points out, "Full concentration on the chief problem at hand makes it possible to solve it; the details should be handled lower down the line. I never fired a man for delegating responsibility, but I did fire men who held the reins too tight and irritated others by preoccupation with minutiae."

4. The amount and expense of paperwork by headquarters staff may be considerably reduced by delegating decision-making. For example, in a medium-sized company the regional managers formerly had to check most of their major decisions with headquarters. It took from 10 to 30 days before a decision was obtained. The transfer of a clerk from one division of regional headquarters to another required eight signatures. Now only three are needed—all from the same regional headquarters. As an over-all result, headquarters staffs have been cut considerably.

5. The expense of coordination may be reduced because of the greater autonomy of decision-making. This requires the establishment of a clear-cut framework of general company policy within which the subsidiary units can make their decisions. For example, at Sears, Roebuck and Co. the establishment of such a policy has resulted in a considerable reduction of the coordinating staff, with greater freedom of action on the part of the individual stores. Sears, Roebuck has emphasized adaptability and ability to carry out simple procedures worked out at headquarters. In this way risks are considerably reduced. A store manager

cannot go far wrong on merchandise selection, for example, because this is done for the most part by top experts at the head office. All he has to do is a good selling job, for which he has much incentive.

On the other hand, the division of a large decision-making unit into smaller ones may have certain disadvantages:

1. Lack of uniformity of decisions. A major obstacle to decentralization is the lack of uniformity of decision from one location to another—e.g., payment of different wage rates and salaries for similar jobs, more liberal holidays and vacations, greater leeway in capital expenditures. However, this factor must not be overemphasized. A careful appraisal should be made of the advantages of uniformities as compared with the cost of achieving them and the possible deterioration of interest and capacity in independent decision-making. Perhaps the advantages of delegation can be enjoyed without loss of uniformity by holding of regular "integrating" meetings between headquarters and regional personnel performing the same function, and between the heads of various functions at headquarters and within each region, with the president presiding at headquarters and the regional general manager presiding at the regional level.

2. Inadequate utilization of specialist advice. The highest-priced and best talent of many companies is often assembled at headquarters. When decentralization is introduced, men in the field may feel that they no longer need to utilize headquarters advice. They may be glad to escape such counsel as they consider unwarranted and time-consuming. The result may be that headquarters staff is only partially utilized and its effectiveness is thus impaired. It is essential, therefore, that management carefully define relationships between headquarters and the field so as to strike an optimum balance between the advantages of waiting for superior advice and of action on the spot.

3. Lack of proper equipment or executives in the field. Headquarters executives (vice presidents in charge of production, sales, etc.) frequently feel that as long as they are in fact responsible for results (regardless of formal delegation), they must have the authority to achieve the desired results. Accordingly, they may be reluctant to delegate much authority—in which case decentralization will remain a fiction. Such opposition can be traced in part to the nature of the function exercised. Certain functions may not lend themselves to delegation, because highly technical problems must be resolved, expensive equipment must be carefully allocated, or it may require acceptance. But perhaps the major reason for reluctance to delegate is the lack of qualified executives in the field. The old ones may be unaccustomed to taking on new responsibilities, and the young ones may not have adequate experience. There is a great deal of difference between recommending action and actually making the decision and assuming responsibility for it. In switching from centralization to decentralization, therefore, provision must be made for training. Perhaps the best way is through the gradual allocation of additional responsibilities, with regular checks or controls on performance to make sure that existing responsibilities have been absorbed successfully before new ones are added.

8.2.2 Nature of the company's business. There are a number of cost factors peculiar to the particular company which, when present, tend to increase the delegation of decision-making. These cost factors include:

1. The flux of company growth. There may be an early period of widespread freedom of decision-making, when the chief executive has to wrestle with the problems of growth and change and is forced to delegate many of his decisions. Once a state of equilibrium is achieved, or a considerable body of tradition has been built up, the chief executive may have time to devote himself to the policies and problems of a more stable business. At this point formalization and central controls may be imposed.

2. Growth by acquisition of properties. When a company's growth is brought about by consolidation of several previously independent units or acquisition of

additional units, the newly acquired properties may be left alone—especially when the acquiring company is profitable and makes it a practice to let everyone go on as before, working out coordination and controls gradually.

On the other hand, the first tendency on the part of the acquiring company may be to impose an increased degree of centralization in an endeavor to reap the economies of increased scale of operation. Here the process toward decentralization may be worked out only gradually as the executives become overburdened and find it more economical to divest themselves of details.

3. Geographical dispersion. The more widely scattered the locations of company branches, offices, and warehouses, the greater the need to delegate decisions, because of the difficulty, expense, and delay of centralized decision-making. Such dispersion of some of the company units may be required because of the need for proximity to sources of raw materials (mining and oil companies, steel producers) or proximity to customers (retail stores). It should be emphasized that geographical dispersion does not necessarily result in delegation of decision-making. For instance, in a number of overseas operations studied, head offices in the United States formulated in great detail working hours, employment standards, and so on, even though local customs and manpower resources were quite different from those in the United States. In some instances, even small expenditures could not be incurred unless checked with United States headquarters.

4. Diversity of production. The small decision-making unit tends to be more economical and hence characteristic of industries in which fashion and design changes are frequent. Again, there are important decision-making delegations in those industries in which conditions of production vary so much that important decisions must be made at frequent intervals, as in coal mining, building, and some segments of the textile industry.

5. Standardization. Conversely, decision-making can be delegated more readily where manufacturing and selling specifications are standardized. Within the framework of centralized policies, administration and execution may well be decentralized. A degree of centralization is frequently maintained through central coordinating committees or central control to check on the efficiency of operations.

6. Legal factors. In many forms of legally permissible combinations, broad powers of decision-making may have to be delegated in order to induce participating companies to agree to the combination, with the centralized decision-making confined merely to central price or output control as in export combinations or central quota allocations. On the other hand, there may be a good deal of centralized control over a subsidiary company, even though it is set up as a separate legal entity (e.g., to facilitate trading in some other country).

8.2.3 Economic trends. There are two major types of economic trends that may lead to decentralization:

1. Expansion of business activity. The expansion of company activities, because of the general upward movement of the business cycle or the company's own long-term growth, tends to lead to decentralization. For the rise in activity increases the number of decisions with no direct effect on the decision-making capacity of top management. Paralleling company expansion, there tends to be a continuing delegation of the less important decisions.

2. Decline of competition. There is a tendency to decentralize as the degree of competition is reduced and the company dominates particular markets, for this is usually accompanied by an increase in company size. Further, the increase in company security and prosperity may make "experimentation" more feasible—and decentralization is often regarded in just that light.

The reverse tendencies may be noted in times of business decline and as competition becomes sharper. Top executives tend to feel that their personal influence and experience are especially needed in such emergencies. As a result, centralized controls are imposed to obtain cost re-

ductions, uniform standards, improved methods of operation, fewer mistakes, checks on expenditure, and follow-ups on execution. Staff specialist positions created to provide staff services to local branches are often cut in times of depression. Thus many organizations revert gradually to centralization in periods of retrenchment. Examples can be cited of many companies that alternately centralize and decentralize with depression and prosperity.

8.2.4 Political trends and philosophy. Political considerations involving important monetary and social costs may be factors in decentralization for such reasons as the following:

1. Avoidance of "over-concentration." There is a pronounced trend in corporation policy to avoid overly heavy concentration in one particular area. Originally, such policy was prompted by the fear of the consequences for local communities when local branches were forced to make heavy employment cutbacks. Thus the General Electric Company, for example, limits its employment in any one community to a certain percentage of the employable population.

Another motive in escaping over-concentration is to avoid labor-relations problems In this category falls the attempt of some companies to split up and move away parts of their large plants from areas where management believes that union leaders are potential and sometimes active disturbers of the peace.

At times, fear of war leads to plant dispersion, largely in heavy goods production, but also in the dispersal of head office personnel.

Another major barrier to over-concentration is, of course, anti-trust legislation.

It should be noted that these dispersals of plants and activities are usually accompanied by some delegation of decision-making.

2. Economic concessions may be obtained by opening up branches in certain states and foreign countries, and some decentralization may follow from the attempt to gain local cost advantages.

3. There may be a long-run underlying trend toward a return to small-scale units and autonomy because of the failures and heavy social costs of bureaucracy; this may have a powerful influence on business thinking and action.

8.2.5 Management philosophy. In many companies the nature of top-management philosophy has a profound influence on the nature of decision-making. Over the years, an increasing number of companies have adopted decentralization of decision-making as a basic method of organization. These companies include very large units like General Motors, Ford, Sears, Roebuck, Du Pont, International Harvester, General Electric, Westinghouse, and others, and medium-large companies such as Sylvania Electric Products, Inc., Sperry Corporation, Johnson & Johnson, and American Brake Shoe Company. The top-management philosophy of these financially successful companies has done much to convince other executives that the adoption of decentralization may be helpful to the economic position of their company. Typical of this thinking is the statement of General Wood, former Chairman of the Board of Sears, Roebuck and Co.: "We complain about government in business, we stress the advantages of the free enterprise system, we complain about the totalitarian state, but in our industrial organizations, in our striving for efficiency, we have created more or less of a totalitarian organization in industry—particularly in large industry. The problem of retaining efficiency and discipline in these large organizations and yet allowing our people to express themselves, to exercise initiative and to have some voice in the affairs of the organization is the greatest problem for large industrial organizations to solve."

Deeply ingrained in this top-management philosophy is the belief in the efficacy of the small society, where there is close personal understanding and teamwork. This was stressed by the president of a large company in an answer to a question by the author concerning the optimum size of the industrial unit, from the standpoint of good industrial relations. He declared that it should not be larger than 2,500 people. Such a small

unit may make possible a better accomplishment of the company's economic and social objectives.

The small, semi-autonomous unit also gives a much better opportunity for all-round executive development. Many of the present leaders of industry got their management training in small companies. To provide this training for leadership and initiative for their successors, many high executives favor small units of operation. It is said that some large corporations maintain several small plants at least partly for the purpose of executive development. Similarly, "multiple-management" and "bottom-up management" stem from top management's belief in continuous executive development through participation. As L. F. McCollum, President of the Continental Oil Company put it, in explaining his company's plan for decentralization (1950): "Probably the best part of the entire plan centers on the opportunity which will be given to all of you to do the job which you know best how to. It will give you more latitude, and it has always been my intention to do that."

There is also a desire to link managerial efforts more closely to results, as in the days of the small independent entrepreneur. These conditions can be reproduced more easily in small, semi-autonomous units. At the same time, this makes possible greater comparability of results from one unit to another.

Finally, there is a growth of social responsibility in which many executives recognize the desirability of some kind of participation on the part of employees and perhaps consumer and financial interests.

8.2.6 Personality. The personalities in a business enterprise are an obvious factor in determining the degree of decentralization. Foremost, of course, is the personality of the chief executive. If he is able to combine policy-making with detailed supervision and control, if he is able to maintain close contact with many of his subordinates, if his intentions can be communicated easily or are known from long experience, the result of all this is likely to be a high degree of centralization. On the other hand, the chief executive may prefer to delegate a large part of his responsibilities, in order to concentrate on one or two functions in which he is superior to anyone else. The guiding criterion is that of "comparative advantage," that is, those responsibilities should be exercised by the chief executive in which he has the greatest relative advantage compared with the other executives. Of course, what is best from an economic standpoint is likely to be modified by the dictates of power, status, and irrationality.

The extent of delegation will also be determined by the competence of the company's executives and their attitudes toward the chief executive. They will be more likely to succeed in their delegated responsibilities if they are assured that top management has confidence in them. Management can best show this confidence by giving them the opportunity and the training necessary to make decisions themselves, and by tolerating a certain number of mistakes which are inevitable at the beginning. The degree of decentralization is thus a function of ability and trust on the part of delegant and delegee.

8.2.7 Type of management function. Finally, the degree of decentralization depends on the nature of the management function concerned. It is difficult to generalize on this point because the nature and importance of the major management functions and of their relationship to one another vary from company to company, and individual circumstances dictate the degree of centralization that is desirable. However, the author has observed that the financial function is usually much less decentralized than most or all other management functions in a company. At the other extreme, delegation of decision-making in the field of sales management appears to be more widespread than in any other major business function. Major decisions of the personnel function, on the other hand, tend to be highly centralized in many companies because management regards its people as its greatest asset, because the ratio of labor cost to total

costs is high, and/or because contractual relations with the union dictate the desirability of heavily centralizing certain types of decision-making.

9. MECHANICS OF ORGANIZATION

9.1 DEFINING THE PRESENT ORGANIZATION

The first step in reorganization work—and one that has a marked influence on all the others—is to define company objectives. Suppose, for example, that a policy of product diversification has been decided on. Organizationally, this will mean that the product division may be the primary division of work, or at least the prevalent division in production and sales activities. Another organizational consequence is that staff functions may be held to a minimum and centralization emphasized as long as the high extra costs of adding new lines are not covered by additional revenue. Similarly, the span of control may have to be reduced as the attention required by diversification increases. The organizational consequences of other basic company objectives may be traced in a similar fashion.

At Sylvania Electric Products, Inc., for example, the basic company objective of decentralization has led to the establishment of separate small organizations in rural areas. The English Rolls-Royce Company continued to decide all policy problems of the American Rolls-Royce Company. For example, it limited the size of the American production organization in order to maintain quality standards.

9.1.1 Basic characteristics of the business. The type of man who heads the business always exercises a profound influence on the organization structure. Thus the organization is likely to be highly centralized where the chief executive is highly energetic, where he is distrustful, where there is a high degree of formality, and where initiative is not encouraged. The background and experience of the leading personalities will in part determine the functions on which they concentrate and those which they will delegate.

A second characteristic is basic technology. Where production and sales are local, as in the cement and building products industries, organization may be geographical. Where products are sold through entirely different channels, organization may be product-oriented. Where traffic or legal considerations are of major importance, these functions may have large staffs, importantly placed in the organization. In oil companies, for example, sales offices are frequently separated from the rather inaccessible sources of supplies in depopulated areas. The number and content of management functions determine the nature and degree of delegation and the span of control. When there is a multiplicity of functions and much technical knowledge required to exercise them, delegation and independence down the line will almost always be required.

Third, the economies of the scale of production determine the degree of concentration of activities in one location and the length of the chain of command.

Fourth, a favorable financial position with large surplus funds and little competition may permit a rather loose, informal organization structure or a much more elaborate organization structure than might otherwise be justifiable.

9.1.2 Describing the existing organization structure. A description of the current organization may already exist in the form of an organization chart and organization manual. Or it may be possible to construct the picture from existing records, announcements of the chief executive, orders from various management representatives, written procedures, and job descriptions. Any or all of the information may be obtained by questionnaire or by interview. The questionnaire method is much less expensive and less time-consuming. If it is used, it is preferable that the information requested be brief and factual. On the other hand, the interview method may yield a good deal more information, may bring out the "feel" of the situation and uncover

vital information about the informal organization and the human relations factors involved. The cost of the interview may be considerably reduced by concentrating on representative cases only. In analyzing results, it should be borne in mind that with both the questionnaire and the interview there may be language difficulties, misunderstandings, and lack of free disclosure, and that these dangers are greater in the case of a questionnaire.

The following is an example of a questionnaire that has been used to obtain information for the purposes of reorganization, resulting in fairly detailed disclosure. (It was accompanied by the announcement of organization changes. This explanation should be passed on from one level of management to another, preferably orally if that is company practice.)

ABC COMPANY

ORGANIZATION QUESTIONNAIRE TO EXECUTIVES

Outline for Describing Your Position

1. Your name
2. Your department
3. Your division
4. Title or name of your position
5. Your location
6. To whom do you report?
7. Title or name of the position of the immediate supervisor
8. Give the names and titles (or names of positions) of those who report to you.
   [In (6) and (8) a distinction might be made of the types of actions which must be reported: (a) actions reported before they take place; (b) after they take place; and (c) those, which need not be reported at all.]
9. Describe fully the responsibilities of your position as you understand them to be at present. (As part of this description you should also include your existing responsibilities and relationships with other units within your division and with other divisions of the Company, with affiliates and with any outside service agencies.)
10. What is the extent of your authority
    (a) For establishing policy?
    (b) For incurring expense?
    (c) For personnel changes including selection, promotion, termination and compensation?
    (d) For establishing methods and procedures?
11. Indicate any committees in the Company or trade groups of which you are a member. If you are chairman, include a description of the purpose, scope of activities and accomplishments of your committee.
12. List by name or title the regular reports which (a) you receive and (b) you prepare, and indicate whether daily, weekly, monthly, etc.
13. List the basic records you are responsible for keeping.
14. Mention anything else of interest in understanding your responsibilities and activities, including any special problems needing attention, any suggestions for improvements or general comments on the over-all Company organizational structure.

At the American Enka Corporation, two major approaches to organizational analysis are undertaken. First there is an inquiry to all departmental managers from the top down, covering identification of the major work processes and activities, and their breakdown into specific responsibilities, as well as the proper relationships between major organizational units. The second approach is from the bottom up, through a procedure study of the daily flow of documents between organization units. Alternately the lowest units in the hierarchy may be studied first and then the subsequent relationships further up, so as to build from the "grass roots" rather than incur the dangers of imposing the top-management pattern. But this may be a wasteful method, because objectives at this low level may be quite out of accord with those of top management. It is therefore a supplementary approach.

A much more elaborate method of describing executive jobs has been developed by Professor Sune Carlson of the University of Stockholm in Sweden.* It

* *Executive Behaviour: A Study of the Work Load and the Working Methods of Managing Directors* (Stockholm: C. A. Stromberg Aktiebolag, Publisher, 1951).

was evolved over a period of years in conjunction with 12 chief executives of non-competing Swedish firms. Each was "analyzed" over a period of weeks by a kind of "time study" of executive activities whereby every action of the chief executive was regularly recorded on a standardized questionnaire blank. This record was supplemented by interviews with and notes by the private secretary, the telephone exchange operator, and interviews with the chief executive himself.

In the analysis, Carlson classified executive activities under five major types of specialization, following Chester I. Barnard.* The nature of the executives' working habits may be summarized as in the tables below.

1. *The place where the executive's work is done.* The executive's total working time during the investigation period (24 days) is averaged in the first table.

2. *Contacts with persons and institutions.* A representative case showed the following distribution of activities in percentage of total working time during the investigation period (second table).

* *The Functions of the Executive* (Cambridge: Harvard University Press, 1938), pp. 127-132.

It should be noted that the chief executive officer spent only one-tenth of his working time alone (the range was from 10 to 35 per cent). The median figure of average daily working time in the study was around 9¾ hours, and the individual figures varied between 8½ and 11½ hours.

Administrative deficiencies found by Professor Carlson in analyzing the distribution of the chief executive's working time included: excessive time spent on outside activities; lack of time for inspecting and visiting works and offices; lack of time for reading and contemplation; excessive nature of the total working load. Other subjects covered in Professor Carlson's study of top management's work habits included communication, executive decision-making, and action.

9.1.3 Defining existing relationships. The fourth step in reorganization should consist of a reconstruction of existing organization relationships. This should be done principally on the basis of the information obtained through interviews, questionnaires and study of organization material. Missing links may have to be supplied by those in charge of the reorganization process. This aspect of the

Place Where Executive's Work Done	Percentage of Total Time
Own office	35
Head office	12
Home plant	3
Somewhere inside the firm	6
Outside the firm on company business	36
At home	8
	100

Contacts with Persons and Institutions	Percentage of Total Time
Inside the firm	
Conferences	27
Working alone	10
Plant	9
Lunches	5
Visiting subordinates	5
Outside the firm	
Conferences and visits	33
Traveling	3
Work at home	8
	100

work may be limited merely to the drawing up of an organization chart However, it might be supplemented by a written breakdown of job content, job relationships, comments, and observations by executives. Those in charge of reorganization should at this point have a clear picture of the status quo. They should be aware of the major organization problems, such as duplication of activities, poor communication, lack of cooperation, and the other organization deficiencies discussed earlier.

9.2 CONSTRUCTING THE IDEAL ORGANIZATION

Perhaps the most important step in the reorganization process is the construction of the "ideal" organization (the term "ideal" is not used here to mean "perfect," but the most desirable as contrasted with the existing organization). Construction of the ideal organization should embody the best thinking of those who have written on the subject and the best practices found in industry. Drawing on these sources, on their own personal background and experience, and on the comments of those participating in the survey, the reorganizers will seek to eliminate the shortcomings inherent in the existing organization structure.

The concept of the ideal organization is closely tied up with the "principles" of organization that have been developed over the last hundred years by many eminent thinkers and practitioners of management. Their purpose has been to guide others in reorganization as well, as to develop sound organization practices. Few would question the desirability of using such guideposts, which are the result of the labors of many able men, rather than leaving reorganization to intuition, to the forces of the moment, and to the necessarily limited experience of the individuals who happen to be concerned with any particular situation and whose direct personal knowledge is necessarily limited.

The principles of organization have been attacked as "obvious," "unscientific," "dogmatic," as falsely representing "the one best way," as overestimating the rationality of people, as forcing executives into a strait jacket. Sometimes the critics are attacking straw men, taking isolated statements out of context and imputing to them meanings that no responsible thinker ever intended. Rarely does the critic substitute anything better. Nor is there much proof that in the absence of principles one can rely solely on one's own experience and intuition. On this point history seems to have taught that "an irresolute general who acts without principles and without plan, even though he may lead an army numerically superior to that of the enemy, almost always finds himself inferior to the latter on the field of battle. Fumblings and the middle course lose all in war." *

Some of the criticism is justified. For, despite the acknowledged authority of writers on organization, it is not maintained that the principles which they have evolved are necessarily applicable to every situation, or are "scientific" in the sense that they can be subjected to repeated proof; in human situations such repeated proof is seldom possible. Nor, it should be noted, has the problem of the interrelationship of the principles been solved. But the critics often fail to realize that those who formulated the principles of organization did not intend them to be as unchangeable as the laws of Moses. This was pointed out long ago by the great French thinker and successful industrialist, Henri Fayol, when he wrote that the soundness of a business "depends on a certain number of conditions termed indiscriminately principles, laws, rules. For preference I shall adopt the term 'principles' whilst dissociating it from any suggestion of rigidity, for there is nothing rigid or absolute in management affairs; it is all a question of proportion. Seldom do we have to apply the same principle twice in identical conditions; allowance must be made for different changing circum-

* Major Thomas R. Phillips, *Roots of Strategy* (Harrisburg, Pa.: The Military Service Publishing Company, 1940), p. 434.

stances, for men just as different and changing, and for many other variable elements. Therefore principles are flexible and capable of adaptation to every need; it is a matter of knowing how to make use of them, which is a difficult art requiring intelligence, experience, decision and proportion." *

Note that Fayol emphasizes "principles" in the sense of "conditions" that are "flexible" and must be adapted to every need. The most important kind of knowledge about organization principles is the knowledge of how to apply them. The principles of organization are somewhat like common sense based on experience, which *may* help its possessor to arrive at a successful solution of his problems. Principles applied without common sense are as likely to fail in this field of endeavor as in any other. From our survey of reorganization it may be asserted that if used in Fayol's sense and with discretion, principles of organization may be helpful in designing the "ideal" organization structure. It should be noted, too, that most of the principles have been evolved by men with a good deal of practical organization experience.

There appears to be a high degree of unanimity among the leading writers of organization on the nature of the major principles of organization. This was brought out clearly in the brilliant synthesis of organization principles by Lt. Colonel L. Urwick in his article on "Principles of Management," in the *British Management Review.* (A list of other books and papers dealing with the subject is included in the references at the end of this section.)

The term, "principles," as used in the foregoing discussion, refers to the criteria which the organization is designed to meet.

Nine criteria appear to have been most frequently used in the process of reorganization. These will be discussed here and an attempt will be made to indicate methods of testing them.

* Henri Fayol, *General and Industrial Management* (London: Sir Isaac Pitman & Sons, Ltd., 1949), p. 19.

9.2.1 Effectiveness. The criterion of effectiveness refers to the accomplishment of the purpose of the enterprise; it is therefore of a social and non-personal nature. It is designed to serve as a broad yardstick of the economic performance of the enterprise. It is concerned with the question of how well the organization meets the test of supplying goods and services. The primary standard is, of course, "fair" profit or net income, as a percentage of sales (current performance) or capital invested (long-run performance) and, in some of the larger companies, percentage share of the market. Subsidiary criteria of the effectiveness of the organization include similar net income measures applied on a comparative basis to various sub-groups, such as plants, divisions, products, or managerial functions. To obviate overreliance on a single measurement, multiple ratios may be used, selected on the basis of consistency and magnitude of contribution.

The effectiveness of an individual function may be measured by computing the dollar expenditure per employee or the number of company employees per employee in that function. For instance, the personnel function in a number of large companies showed a personnel expenditure of $50 per employee and approximately one industrial relations employee for every 100 company employees. These ratios may, however, be quite unreliable as guides.

Following the economist A. C. Pigou,* the product contribution of the organization to the community might be measured in terms of "social revenue" and "social costs"—i.e., by the income yield and expense to the community. For example, an organization change might, of itself, have adverse effects on employment in a local community. Recognizing this, management might substitute a new local activity, such as a research department, to compensate for the removal of

* *The Economics of Welfare* (London: Macmillan and Company, Ltd., 1938), pp. 127-212.

its headquarters elsewhere. Management might also decide to pay the expenses of employees who will move to the new location, including any losses on the sale of their old homes and the purchase of new ones. These would be organizational contributions by the company to the community's social revenue. On the other hand, the abrupt abandonment of an industrial site might saddle the community with the cost of unemployment, unutilized buildings, and other social burdens.

The effectiveness of an individual function should be measured by comparing its contributions to company revenue against its costs. Thus a manufacturing division's costs (wages, salaries, share of overheads) would be compared with the value of product added. The effectiveness of an organization department can be measured only partially in terms of its contributions to net company revenues —such as better decisions and cost reductions through conservation of manpower and reduction of errors. Its contributions in terms of morale and cooperation are hardly measurable. Measurements in terms of profitability are also likely to vary over time; for example, the immediate cost savings of the organization department might be lost in the long run through subsequent deterioration of teamwork and morale.

9.2.2 Efficiency. The criterion of efficiency requires the fulfillment of the personal and individual objectives of those who are connected with the enterprise. This definition, it should be noted, departs somewhat from general business usage. "Efficiency," used in this sense, rests on the premise that the company has met the criterion of effectiveness and can fulfill its financial obligations. Survival may also require that the business fulfill obligations of a broader nature.

Standards for measuring the efficiency of the organization, as defined here, have not yet been developed to a point where they can be accurately applied. However, some of the major considerations have been formulated. One of the best statements in this connection is that of J. M. Clark.*

Clearly, proper attention to the organization structure is essential to the fulfillment of the personal and individual objectives of all who are connected with the enterprise. In the case of executives, for example, a proper organization structure means clear-cut lines of authority and responsibility, participation in policy-making, the right to be heard, the opportunity to develop to the full measure of their potentialities, and other conditions that contribute directly to their personal satisfaction as well as their individual effectiveness.

"Efficiency" is seen to be a rather vague criterion that differs as different persons interpret it. For example, the chief of the enterprise may favor values that are not accepted by his subordinates. He may prefer autocracy for the sake of speedy and disciplined action, while subordinates may prefer greater participation and a slower tempo. Different persons also set different goals of effectiveness. One president may aim at maximizing the profits of his organization, another at "fair shares" for all parties connected with the enterprise, another at survival leading to maximum expansion or maximum employee satisfaction.

9.2.3 Division of work. "The primary step in organization is to determine and to establish as separate entities, the smallest number of dissimilar functions into which the work of an institution may be divided." † The nature and number of the basic functions is determined by their relative importance in contributing directly to the purpose of the enterprise. Two basic functions in the manufacturing business frequently are production and sales. In a retail business buying is a basic function, taking the place of production in an industrial con-

* *Social Control of Business* (New York: McGraw-Hill Book Company, Inc., 1939), p. 220.

† H. A. Hopf, *Organization, Executive Capacity and Progress* (Ossining, N. Y.: Hopf Institute of Management, Inc., 1945), p. 4.

cern. To these, finance, personnel and/or procurement are sometimes added. The importance of the other functions varies tremendously. Thus, advertising is a major function in the soap business, contributing very directly to the major purpose of the enterprise, namely sales. In some parts of agriculture advertising is a minor function, since it has no perceptible influence on sales of products, such as wheat.

Auxiliary functions should be evolved in accordance with the foregoing factors. Such auxiliary activities contribute to and/or facilitate the performance of the basic functions, but do not contribute directly to the purpose of the enterprise.

9.2.4 Functional definition with authority and responsibility. The functions or job contents necessary to reach objectives must be defined. This step is governed by two precepts: (1) "Define duties clearly." * (2) "The work of each man in the management should be confined to the performance of a single leading function." †

Functional or job definition is elaborated as follows by Henri Fayol: "Authority is the right to give orders and the power to exact obedience. Distinction must be made between a manager's official authority deriving from office and personal authority, compounded of intelligence, experience, moral worth, ability to lead, past services, etc. In the make-up of a good head, personal authority is the indispensable complement of official authority. Authority is not to be conceived of apart from responsibility, that is apart from sanction—(or 'accountability for the performance of duties,' as Mary Parker Follett expresses it). . . . Responsibility is a corollary of authority, it is its natural consequence and essential counterpart and wheresoever authority is exercised responsibility arises.

"The best safeguard against abuse of authority and against weakness on the part of a higher manager is personal integrity and particularly high moral character of such a manager, and this integrity, it is well known, is conferred neither by election nor ownership." *

9.2.5 The chain of command. The chain of command, as described so well by Fayol "is the chain of superiors ranging from the ultimate authority to the lowest ranks. The line of authority is the route followed—via every link in the chain—by all communications which start from or go to the ultimate authority. This path is dictated both by the need for some transmission and by the principle of unity of command, but it is not always the swiftest. It is even at times disastrously lengthy in large concerns, notably in governmental ones. Now, there are many activities whose success turns on speedy execution, hence respect for the line of authority must be reconciled with the need for swift action.

"Let us imagine that section *F* has to be put into contact with section *P* in a business whose scalar chain is represented by the double ladder *G-A-Q*.

```
         A
       B   L
      C     M
     D       N
    E         O
   F - - - - - P
  G             Q
```

"By following the line of authority the ladder must be climbed from *F* to *A* and then descended from *A* to *P*, stoping at each rung, then ascended again from *P* to *A*, and descended once more from *A* to *F* in order to get back to the starting point."

9.2.6 Channels of contact. Fayol continues, "It is much simpler and quicker to go directly from *F* to *P* by making

* Fayol, *General and Industrial Management*, p. 54.

† Frederick W. Taylor, *Shop Management* (New York: Harper and Brothers 1911), p. 99.

* Fayol, *General and Industrial Management*, pp. 34-35. See also James D. Mooney and Alan C. Reiley, *The Principles of Organization* (New York: Harper and Brothers, 1939), pp. 14-24, and the earlier edition, *Onward Industry!* (New York: Harper and Brothers, 1931), a pioneer study of organization.

use of *FP* as a 'gang plank' and that is what is most often done. The chain of command will be safeguarded if managers *E* and *O* have authorized their respective subordinates *F* and *P* to treat directly, and the position will be fully regularized if *F* and *P* inform their respective superiors forthwith of what they have agreed upon. So long as *F* and *P* remain in agreement, and so long as their actions are approved by their immediate superiors, direct contact may be maintained." *

The nature and need for channels of contact are well described in the organization manual of the Jones & Laughlin Steel Corporation:

> a. The plan of organization should permit and require the exercise of common sense and good judgment, at all levels, in determining the best channels of contact to expedite the work. These channels of contact are not described or limited by the lines of responsibility and authority of the organization structure as shown on the organization chart.
>
> b. Contacts between all units of the organization should be carried out in the most direct way consistent with good sense. In making contacts beyond the lines of responsibility and authority on the chart, it should be the duty of each member of the organization to keep his senior informed on:
>
> (1) Any matters on which his senior may be held accountable by those senior to him.
>
> (2) Any matters in disagreement or likely to cause controversy within or between any units of the organization.
>
> (3) Matters requiring advice by the senior, or his coordination with other organization units.
>
> (4) Any matters involving recommendations for changes in, or variance from, established policies.
>
> c. Staff instructions to units under supervision of others should be channeled through that supervisor if the instructions are of direct concern to and require personal attention of that supervisor. Such channeling can be minimized by the routing of copies to the supervisor with the action papers going direct.*

* Fayol, *General and Industrial Management*, p. 35.

This principle may overcome difficulties arising from the principle of unity of command—namely, that one man should have only one boss.

9.2.7 Balance. "A special task of continuous reorganization is to see that the units of the organization are kept in balance—that there is a reasonable relative apportionment of strength among its departments.† " 'Balance' on the battlefield implies the disposal of available forces in such a way that it is never necessary to react to the enemy's thrusts and moves; a balanced army proceeds relentlessly with its plans." ‡

Balance requires (a) the proper proportions between centralization and decentralization and (b) flexibility:

1. *Centralization*—"Responsibility, authority, and accountability should be centralized at key points to provide leadership, direction, and control. This will also aid in establishing major objectives and policies and maintaining consistency of action. It will also facilitate dealing with emergencies and exceptions from plans, standards, and routine. These are the matters requiring top executive attention."

2. *Decentralization*—"There should be a decentralization of responsibility, authority, and accountability to place the ability to decide and act within the scope of approved plans and policies as closely as practicable to the point where need for decision or action originates." **

3. *Flexibility*—"The vitality of an enterprise is measured by its power of spontaneous reaction to changes in conditions, and of internal modification and

* Jones & Laughlin Steel Corporation, *Organization Manual* (Pittsburgh, June 1950), pp. 4-5. This principle was originally formulated by General Brehon B. Somervell and others in the *U. S. Staff Manual*.

† Henry S. Dennison, *Organization Engineering* (New York: McGraw-Hill Book Company, Inc., 1931), p. 185.

‡ Montgomery of Alamein, quoted in Urwick's *Principles of Management*, p. 47.

** Jones & Laughlin Steel Corporation *Organization Manual*, p. 4.

rearrangement to meet such changes." * "To wring the maximum possible advantage from standardization and simplification, and at the same time to retain always the full measure of flexibility postulated by the circumstances." †

9.2.8 Control. The principle of control involves:

1. *Comparison*—"All figures and reports used for purposes of control should be related to standards of performance required and, if comparable, to past performance." ‡

2. *Information*—"All information used for purposes of control should be strictly objective both in source and presentation. Any statement concerning persons implying criticism should be accompanied by the comments of those affected. Rules of evidence should govern the acceptance of any statement." **

3. *Integrity of Command*—"Control is a valuable auxiliary of command. Properly exercised, it can give the leader necessary information which the hierarchy of supervision would sometimes be incapable of supplying." But for control "to become confused with the command and operation of the various services is an encroachment involving duality of direction in its most serious form. . . . The tendency of control to encroach is widespread, particularly in large organizations." §

* Lt. Col. L. Urwick, "The Principles of Direction and Control," in *Dictionary of Industrial Administration* (London: Sir Isaac Pitman & Sons, Ltd., 1928), p. 178. And *Cost and Production Handbook* (New York: The Ronald Press Company, 1934), p. 1345.

† Lt. Col. L. Urwick, *The Elements of Administration* (London: Sir Isaac Pitman & Sons, Ltd. 1943), p. 31.

‡ Urwick, "The Principles of Direction and Control," p. 179. and *Cost and Production Handbook*, p. 1345.

** Adapted from Urwick, "The Principles of Direction and Control," p. 179. And E. F. L. Breech, *Management, Its Nature and Significance* (London: Sir Isaac Pitman & Sons. Ltd., 1948).

§ Henri Fayol, *Administration Industrielle et Generale* (Paris: Dunod Frères, 1925, p. 157, translated and adapted by L. Urwick)

4. *Uniformity*—"All information used for purposes of control should be in terms which correspond with responsibility, e.g., main heads of account should be identical with the organization structure. No individual s effort should be expressed in figures which he is not in a position to influence." *

5. *The Exception Principle*—"The manager should receive only condensed, summarized and *invariably* comparative reports covering, however, all of the elements entering into the management. [They] should have all the exceptions to the past averages or to the standards pointed out . . . thus giving him in a few minutes a full view of progress which is being made or the reverse." †

6. *Utility*—"Figures and reports used for purposes of control vary in value directly in proportion to the period separating them from the events which they reflect. They should be designed with the objects of assisting decision in the present and avoiding waste in the future, and not as a record." ‡

7. *Avoidance of "Red Tape"*—"Avoid red tape—to combat the abuses of over-regulation, bureaucratic formalism and paper-mongering. . . ." ** "That is what bureaucracy essentially means—a reliance upon procedures and precedents and a distrust of the exercise of personal power of true leadership caliber." §

9.2.9 Perpetuation. "The plan of organization should provide a 'ladder' of positions of increasing scope of responsibility, authority, and accountability so related to each other that at all times there are replacements in training for each higher position. One of the most important responsibilities of top man-

* Adapted from Lt. Col. L. Urwick, "Principles of Direction and Control," p. 179, and *Cost and Production Handbook*, p. 1345.

† Taylor, *Shop Management*, p. 126.

‡ Urwick, "Principles of Direction and Control," p. 179, and *Cost and Production Handbook*, p. 1345.

** Fayol, *Administration Industrielle et Generale*, p. 79.

§ Ordway Tead, *The Art of Leadership* (New York: Whittlesey House, McGraw-Hill Book Company, Inc., 1935), p. 51.

agement is the successful perpetuation of the Corporation through making available qualified personnel for future management needs. These needs must be filled by executives with a breadth of experience gained from a variety of management responsibilities as well as depth of training in a specialized management area." *

9.3 PUTTING THE ORGANIZATION PLAN INTO EFFECT

We have discussed at great length the nature of the ideal organization. These considerations do not mean, however, that an attempt should be made immediately to force the existing organization to conform to the ideal. It cannot be overstressed that the real value of the ideal structure is essentially as a guide to the long-range plans of the company. As such, it should be reexamined whenever there arises an immediate necessity or opportunity for a change in organization through retirement, transfers, and so forth. Then, and perhaps only then, should major steps be taken to make the existing structure move toward the ideal.

However, it should be noted that when a company gets into a reorganization process it will frequently adopt an organization plan of an intermediate character which is somewhere between what exists and what ideally should be. This will usually include the correction of the worst organizational deficiencies that have been described.

9.3.1 Setting up the basic functions. To start the actual reorganization, the major functions and positions of the ideal organization need to be "brought down to earth." Where the necessary positions do not at present exist, the cost of creating and filling them must be determined. This may be prohibitive in some cases—e.g., a top industrial engineer is likely to earn more as a consultant than most corporations can afford to pay. Or the chief executive may object to the creation of a certain job. Or the pay structure may be thus upset. As a result, a function may have to be split into several minor ones. For example, instead of a $50,000-a-year controller, three accountants may be hired at $12,000 each. Basic changes are further restricted by the limitations of present personnel. However profitable the organization changes might be, they frequently cannot and will not be carried out until the personnel situation changes.

Once the basic functions have been set up and agreed upon, each job should be written up as it should be performed within the framework of the organization structure adopted. Job descriptions should be started at the top level and then worked downward. In describing the content of each job, the incumbent's agreement should be obtained and then that of his superior. Final approval may have to be given by other executives. Any points at which no agreement can be obtained should be resolved at a higher stage, ultimately by the president, if necessary. Only if there is genuine acceptance all around should the final job draft be signed and issued.

9.3.2 Matching incumbents against job requirements. The next logical step is to match the incumbents of existing positions against the job requirements —which may have been increased or reduced on the ideal organization. Some consultants and reorganization specialists are reluctant to engage in such a procedure, because they feel that they are not sufficiently familiar with the work of the executives concerned to render such a judgment. Others make a very rough appraisal of the man and his job, usually in committee so as to reduce errors of judgment. An approximate rating scale may be employed (occasionally a detailed percentage evaluation) such as (1) "outstanding," (2) "good," (3) "average," (4) "poor," (5) "incompetent." (1) and (2) are considered to be promotional material, (5) may be slated for a job with reduced responsibilities or separation.

Occasionally a detailed matching proc-

* Jones & Laughlin Steel Corporation, *Organization Manual*, p. 7.

ess is employed to fit man and job. One such example is reported by L. Rene Gaiénnie, Director of Personnel of Fairbanks, Morse and Co. To save time and avoid undue variations, the same rating elements are used in the evaluation of the average performance required on the job and the rating of the job incumbent, for example: (1) job knowledge, (2) intelligence, (3) skill in handling people, and (4) versatility. If the resulting ratio is equal, the incumbent just fills his job requirements. If it is unequal, it indicates whether, and to what degree, the job is heavier than the man, or vice versa.

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During World War II, Dr. Dean headed the machinery pricing section of the Office of Price Administration, and later had charge of developing and operating gasoline and fuel oil rationing. Before the war he was Executive Secretary of the Conference on Price Research of the National Bureau of Economic Research. He was Director of the Institute of Statistics and a member of the faculty of the University of Chicago for five years. His consulting firm was established in 1939 and has operated under the name of Joel Dean Associates since 1946.

A recognized authority on marketing, Dr. Dean has written many articles on pricing and marketing policies. For several years he was an editor of the *Journal of Marketing*. His pioneering work in the statistical determination of cost is widely recognized as setting a standard for later researchers. Among his most recent publications are: "Measuring the Productivity of Capital" (*Harvard Business Review*, January-February, 1954); "Methods and Potentialities of Break-Even Analysis" (in Solomon's *Studies in Costing*, Sweet and Maxwell, 1952); "Pricing Policies for New Products" (*Harvard Business Review*, November 1950); "Measuring the Real Economic Earnings of a Machinery Manufacturer" (*Accounting Review*, April 1954); and "Competition Inside and Out" (*Harvard Business Review*, November-December 1954).

SECTION 2

Managerial Economics*

Joel Dean

1. PROFITS

1.1 NATURE OF PROFITS

Profits are the primary measure of the success of a business firm. But the word "profit" has different meanings to investors, tax collectors, workers, politicians, and economists. Consequently, before we can decide what is and is not a profit, and before we can improve a company's profit position, we must first understand how profits arise.

1.1.1 Types of profit theory. Economic theories on profits can be classified into three broad groups: The first looks upon profits as the reward for bearing risks and uncertainties; the second views profits as the consequence of frictions and imperfections in the competitive adjustment of the economy to dynamic changes; the third sees profits as the reward for successful innovation.

According to the first type of theory, profits are the factor payment for taking a risk—for agreeing to take what is left over after contractual outlays have been made. This profit theory is based upon the notion that most people prefer stable, moderate incomes to high incomes that have high risk. Hence those that are willing to assume the risk get higher earnings, not only when they are lucky but (as a group) over the long run as well.

The major risk for a businessman comes from holding special-purpose assets as opposed to holding general purchasing power. To be sure, price-level

* This section of the Handbook is drawn largely from two books: Joel Dean, *Managerial Economics* (New York: Prentice-Hall, Inc., 1951); and Joel Dean, *Capital Budgeting* (New York: Columbia University Press, 1951). For help in preparing this condensation, I want to thank Stephen Taylor.

risks arise from holding cash or its equivalent, but an even greater risk exists in holding a resort hotel that is subject to the hazards of changes in tastes and technology as well as of business cycles.

According to the second type of theory, profits are either just a frictional effect of changes in the economy, or they result from imperfections in the market system that allow individuals to establish monopoly positions. Although frictional profits are transient and add to a zero sum over the long run, monopoly profits can supposedly be maintained and accumulated over the years if the monopoly is protected.

In the third type of profit theory, profits are viewed as a wage for the service of innovation. They are thus a functional income, as in the risk theory. But risk plays no essential part in the innovation theory. Innovation refers broadly to any purposeful change in production methods or consumer tastes that increases national output more than it increases costs. The increase in net output is the profit that comes from innovation.

Risk and uncertainty are not necessary to this theory. The innovator may be able to forecast just what his gain will be while other firms are blissfully ignorant of the impending obsolescence hanging over them. If there is any risk, it is carried by the investor, not by the entrepreneur.

The concept of innovation becomes very broad in this theory, since it includes not only new products, such as synthetic fibers, but also new organizations, new markets, new promotion, and new raw materials. To an important degree, innovation has been built into the competitive system, complete with research laboratories and advertising staffs. In many industries everyone has to run fast to stay in the same place. True innovation should be distinguished from style rivalry. Credible evidence of true innovation is a high rate of company growth from plowed-back earnings

Theories that ascribe profits to risk-bearing or chance when uncertainty exists can be fitted into advanced concepts of the stationary economy, but they have little relevance to an economy that is growing in size and developing new products and technology. For the dynamic manufacturing industries, which are the principal concern of this book, the most telling concept depicts profits as the gains in national income that are generated by the managerial drive for distinction through creative innovation.

1.2 PROFIT MEASUREMENT

Economists are unhappy about conventional accounting methods for measuring business income. Many think them inadequate and sometimes misleading for penetrating analysis, which often requires a complete reshaping of the conventional income statement. In this section we shall sketch the broad outlines of this classic controversy and suggest the kinds of modifications of conventional income statements that are important to economists and appropriate for different managerial purposes.

The most important points of difference between the economist's approach and the accountant's approach center around: (1) the inclusiveness of costs, i.e., what should be subtracted from revenue to get profit; (2) the meaning of depreciation; (3) the treatment of capital gains and losses; and, perhaps most important, (4) the price-level basis for valuation of assets, i.e., current vs. historical costs.

In measuring profits, the role of futurity in economic values and in business decisions underlies all three of these issues. Economists look to the future as the basic source of value of today's assets, and the businessman recognizes that for his decisions the past is irrelevant, except as a forecaster of the future. But the accountant has a problem here. In an effort to maintain sound, conservative "standards of factuality," accountants want to report historical facts and eschew "speculation" about the future.

To an accountant, net income is essen-

tially a historical record of the past. To an economist, net income is essentially a speculation about the future, since, for corporations, economists measure net income as the maximum amount that can be distributed in dividends (theoretically from now into the indefinite future) without impairing the company's earning power. Hence, the concept aims at preservation of stockholder's real capital. To estimate income, then, requires a forecast of all future changes in demand, changes in production processes, cash outlays to operate the business, cash revenues, and price changes (to state cash flows in terms of constant purchasing power). That is, we need a cash budget (adjusted for purchasing power) that forecasts farther into the future than anyone can see. If this budget were available, a program could be planned for borrowing and investing cash so as to allow for an annual cash dividend payment equal to the uniform consumption of real goods that we here conceive of as the index of the firm's income.

The accountant's concept of income, like the economist's, requires for its measurement a consolidation of dated transactions of cash outlays and cash receipts. But there is a basic difference: The accountant uses *past* transactions instead of *future*.

1.2.1 What to include in costs. The first specific issue in profit measurement is determining what costs are to be deducted from revenues. Wages, materials, and interest on borrowed capital are indisputable costs, but earnings of management and interest on owners' capital are less clearly so.

An executive's earnings are a combination of salary, bonus, and dividends, in proportions aimed partly at tax savings. They contain elements of both cost and profits. But how you distinguish the two depends on the kind of profit theory to which you subscribe. Profits from assuming risk are measured by the executive's differential income from the firm over the earnings that could be gained by putting his time and money into perfectly stable and safe activities. His profits from innovation are more difficult to measure, since they are the differential income over earnings that he could make in established activities of comparable risk. These bases of comparison are not easy to set up. Although management's earnings are to some extent separate from the firm's earnings, they may well have to be considered in appraising the profitability of a company.

Similarly, the cost of equity capital to the firm depends on whether you consider the alternative uses of the capital to be a high-grade bond issue or common stocks of comparable riskiness.

1.2.2 Depreciation. Accountants make periodic depreciation charges to income in order to recover the cost of equipment before its usefulness is exhausted. The procedure is to estimate the equipment's useful life in years and to make the annual charge just large enough to recover the original cost within that estimated period.

The objective of this procedure is to allocate the total original cost of equipment to production during the period in which it will be used. The effect is to insure that revenues equal to original cost are not distributed as dividends, but rather are put back into assets, such as more equipment or cash.

The allocation of original cost is not an important question economically, since original cost does not, *per se,* affect current decisions. The correct objective of management in this problem is to earn a rate of return on stockholders' capital at least as high, all risks considered, as the stockholders could have made in other types of investment. If the company cannot yield that high a return, capital should properly be turned back to the stockholders.

In principle, management should take three steps: (1) It should measure the current company rate of return as the discount rate that, applied to future earnings (before depreciation charges), will make the sum of these earnings equal to the present disposal value of the company's assets. (2) It should plow back earnings into new investments that promise rates of return at least as high

as stockholders could get in comparable companies, and should make enough of these internal investments to maintain the dollar amount of the company's future earnings. (3) It should distribute as dividends those earnings that cannot, within a reasonable time, be plowed back in projects that better the cost of capital.

This version of management's job is not easy to live with and is not found in accounting or administration literature. It is, nevertheless, the way that economists view the question, and it is stated here as a reference point for considering problems in depreciation accounting. There is a gulf between this economic view and the notion that a depreciation charge somehow measures capital consumption, a gulf that overshadows other depreciation arguments, e.g., straight-line method vs. declining balance method.

To summarize, depreciation accounting has a noble objective, but it is far too crude a device in an economy of changing prices, changing products, and changing methods. As a neatly computed but fictitious cost, the depreciation charge obscures too many analytical questions. In economic thinking, the depreciation charge has just two functions: It produces a cash tax saving as an allowable expense, and it may temporarily restrict distribution of income to stockholders.

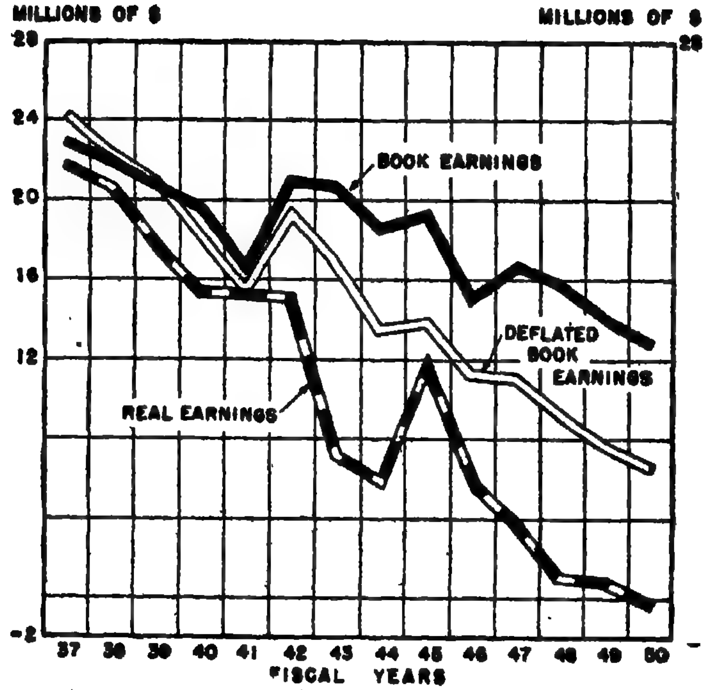
1.2.3 Treatment of capital gains and losses. Capital gains and losses, or "windfalls," as they are often called, may be defined loosely as unanticipated changes in the value of property relative to other real goods. That is, a windfall reflects a change in someone's anticipation of the property's earning power. Fluctuations in stock-market prices are almost all of this nature.

A sound accounting policy to follow concerning windfalls is never to record them until they have been turned into cash by a purchase or sale of assets, since it is never clear until then *exactly* how large they are in dollar terms. However, a fact-minded management ought to have some sort of balance sheet, if only an estimated one, that realizes surprises long before they have become exact enough to be acceptable to accountants. For example, if prices are to be determined with the objective of producing a "reasonable" rate of return on the valuation of investment, they should reflect projectable windfalls even though not yet cashed. Otherwise, a target rate of return based on a historically "factual," but nevertheless fictitious, capital value may lead to later unpleasant surprises from the resulting price policies.

1.2.4 Current vs. historical costs. As measured by accountants, profits are a residual in a calculation that uses dollars of many different dates—today's cash dollars, last year's inventory dollars, and equipment dollars of many years of prosperity and depression. To measure real profits, all these assets must be stated in dollars of the same purchasing power. This is an elaborate operation, and the desirable data on prices, products, and dates are usually hard to estimate. With some expediting assumptions, however, usable approximations can be made. In respect to price-level impacts, three kinds of earnings estimates may be distinguished: (1) jumbled-dollar profits, (2) contemporary-dollar profits, and (3) constant-dollar profits. The earnings reported by conventional accounting are, as we have seen, a jumble of dollars of different dates and usually of different purchasing power.

Contemporary-dollar profits can be estimated by making price-level adjustments that would make the revenues and costs of a particular year reflect dollars of that year's purchasing power. For many enterprises, contemporary-dollar profits can be approximated by a combination of replacement-value depreciation and LIFO (last-in-first-out) costing of materials.

By the LIFO method, the last materials purchased are the first charged to the cost of goods sold. When the inventory turnover is slow, business income is measured on the basis of more recent prices of materials than under the first-in-first-out (FIFO) method. When prices are rising, LIFO produces a lower income than FIFO (since stated material costs are higher), and when prices are



Accounting Review, Vol. XXIX, p. 261.

FIG. 2.1 REPORTED EARNINGS COMPARED WITH REAL ECONOMIC EARNINGS OF A MACHINERY MANUFACTURER

falling, it shows a higher income. LIFO thus tends to wash out the paper profits that result from comparing a closing inventory with an equal opening inventory stated at different prices. However, to attain the ideal of economic realism, a full restatement of inventory in constant prices is required.

An interesting estimate of the effect of contemporary-dollar profit deflation, made by the Machinery and Allied Products Institute in May, 1949, was that the figure $50 billion for total corporate profits for 1946-1948 was 38 per cent fictitious. Nineteen billion was actually inventory profits (i.e., increase in the dollar value of a constant physical inventory) plus under-depreciation (failure to charge enough depreciation for replacement purposes).

A thoroughgoing deflation of financial statements requires a restatement of all accounts, year by year, in terms of a dollar of constant purchasing power and then a recomputation of profits. Such a deflation is a lengthy operation, but during inflation the results can be striking, as shown by the disparity between book and real earnings (Fig. 2.1). The middle column shows how inadequate deflation results from dividing reported profits by a single index number.

When a deflation of this kind is combined with economic analysis, executive judgment, and imagination, income approximations that are usable for business decisions can be made. Management problems take innumerable forms, and an accounting system that would fit them all is hard to conceive. The accounts should instead be made a source of basic data that can be fitted in different ways to different particular needs.

1.3 PROFITS FOR CONTROL

Large corporations must always face the problem of bureaucratic deviationism, the tendency for middle and lower management to think in terms of security and routine or personal ambitions that conflict with the company's profit-making objectives. Three common deviationist tendencies appear when the profit motive is thus attenuated: (1) Energy is spent in expanding sales volume and product lines rather than in

raising profitability, the valid company objective. (2) Subordinates establish perfectionist standards of quality that cost far more than they are worth. (3) Lower management tries to be cautious and oversafe, since there are no rewards for imaginative ventures commensurate with the perils of making mistakes.

Companies that have become concerned about this problem have come up with two methods to avoid hardening of the profit-seeking arteries. The first is realignment of operating responsibility from a functional basis to a commodity basis. The effect is to give the executive authority over all functions in his division, and to make him responsible for profits.

The second method is reorientation of accounting reports to conform to the areas of executive responsibility. Each executive is given a profit goal for his operation. His performance is appraised not only by comparison with this goal by means of periodic profit-and-loss statements, but also by an analysis of the determinants of profits by means of subordinate budgetary controls.

Managerial decentralization achieved by profits controls is significantly superior to alternative devices. The establishment of profit centers with economically realistic intra-company prices and costs will permit measurement of executive performance in terms of achievement of profit goals that are adequately adjusted for circumstances. This sort of profits control increases the likelihood that independent decisions of component units will be in harmony with the objectives of the corporation as a whole. Measuring performances of component divisions in terms of economic profits forces integration of conflicting objectives (e.g., volume aspirations in the face of rising selling costs) at lower executive levels where greater familiarity with details is found.

1.4 PROFIT FORECASTING AND BREAK-EVEN CHARTS

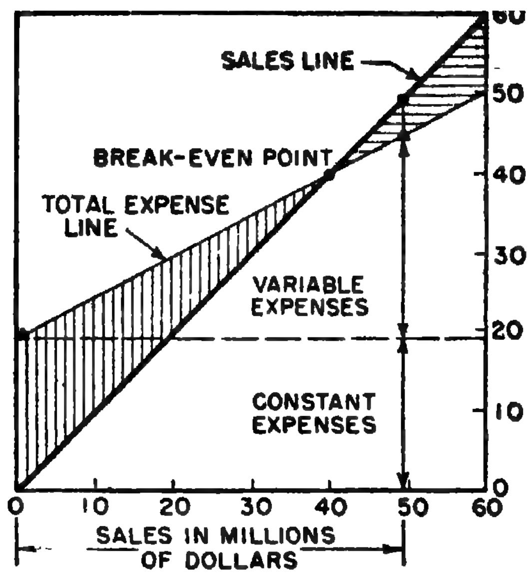
Three approaches to profit forecasting may be distinguished. (1) Spot projections: prediction of the entire income statement for a specified future period by forecasting each important revenue and cost separately. (2) Break-even analysis: identifying functional relations of both revenue and costs to output rate, with profits related to output as a residual, or, alternatively, relating profits to output directly by the usual data used in break-even analysis. (3) Environmental analysis: relating the company's profits to key variables in its economic environment, such as general business activity and general price level.

In recent years, break-even analysis has come into wide use by company executives, investment analysis, labor unions, and government agencies.

1.4.1 Break-even analysis. A break-even chart (the central tool of break-even analysis) is a diagram of the short-run relation of total cost and of total revenue to rate of output. Figure 2.2 is a typical break-even chart, in which the vertical spread between the revenue line and the cost line defines the profit function.

Most break-even analyses are aimed at the same goal, short-run cost and profit behavior. But decidedly different kinds of data are used by different people in constructing break-even charts. At one extreme is the inductive method of asking accountants and engineers to estimate what costs should be at two or three hypothetical levels of output. At the other extreme is the simple empirical method of plotting costs against revenues over a long period of years, giving what is called a "migration-path" chart. Between the extremes is the statistical analysis of historical data that have been carefully selected for their relevance to the present product mix and plant, and have been corrected for irrelevant price changes and cost lead times.

The migration path probably has very little validity for current profit forecasting, since it is primarily a history of the growth of a firm and reflects all the changes that have occurred in plant, technology, product line, and labor unionization. What is needed is a chart



Dean, *Managerial Economics*, p. 328.

FIG. **2.2** BASIC STATIC RELATION (BREAK-EVEN CHART).

for the conditions that management expects to meet during the coming forecast period.

The value of the inductive and statistical break-even charts depends partly on the care and skill with which they have been constructed, and few break-even charts seem to have met the important problems adequately. Probably the most serious pitfall has been the use of sales as a measure of output (the horizontal axis) in a company-wide break-even chart, even when the analysis covers a decade or more of fluctuating dollar values, changing product mix, and changing patterns of plant utilization. To be meaningful for any extended period, a break-even chart should be limited to an individual plant, with an appropriate regrouping of company cost and sales records. And output should be measured in some kind of physical units for a product mix that is similar to the current and future mix. Perhaps the best practical measure of output for a multi-product plant is production valued at some set of constant sales prices for the various products. For instance, an output series from 1925 to 1950 could be measured by valuing all products through the entire period at their 1950 prices. Of course, if output is in constant dollars, the total expense line must also be in constant dollars. That is, it must be adjusted to eliminate variations caused only by changes in wages and materials prices, since without this adjustment the cost of a given output in 1948 would be much above its cost in 1929—a spurious discrepancy for forecasting purposes.

With output thus measured physically, the slope of the sales line on the chart is no longer always 45 degrees. It can instead be varied to test possible changes in general price levels.

Nevertheless, with all these lengthy and costly adjustments of the records, break-even charts must be taken with a grain of salt. In the first place, a single chart is generally good for only one product mix, and ideally a whole set of charts is needed for the possible alternative combinations of products. Neither the data nor the money is usually available for such exhaustive analysis. Secondly, costs are commonly far more manipulable than they seem to be on a simple black-and-white chart. There are always substitutable materials, product changes, avoidable overhead costs, and many other factors that are within management's discretion to tighten up on when the compulsive force of a recession makes itself felt.

1.4.2 Environmental analyses. Factors that control profits have a tendency to move in regular and related patterns; rate of output, prices, wages, material costs, and efficiency are all interrelated by their connections with the national markets and by their interactions in the aggregate business economy. Theories of business cycles are based on the hypothesis that the national values of production, employment, wages, and prices show systematic patterns of behavior as business activity fluctuates. Although it is not always clear what the pattern is in detailed analyses, this hypothesis has some justification for broad averages.

These patterns of confluence raise the possibility that the profits of a company can be forecast directly by finding a relation to key variables in the economy that either control or combine the movements of the myriad of direct forces that are felt in the income statement. The problem is to find a direct functional relation between company profits and national activity that shows statistical significance.

This approach to profit forecasting is in sharp contrast to the particularistic break-even analysis. The relations are approximate and empirical; their value rests not so much on plausibility (although this helps) as on stability of the relation and ability to forecast the independent variable.

The results of a study of this kind are shown in Table 2.1. In this analysis, aggregate industry profits were related to variations in the Federal Reserve Board's Index of Industrial Production by a chain process of (1) relating each industry's production to the index by correlation of historical data, (2) relating each industry's profits to changes in its output, and (3) thus relating profits to the FRB index.

The principal shortcoming of correlation analysis for this kind of profit forecasting is the dearth of clearly relevant data. In such studies, history that is more than one business cycle old can rarely give reliable clues to the future. Since a single cycle seldom encompasses more than a decade, a plausible correlation usually requires quarterly or monthly data, with necessary and sometimes dubious adjustment for seasonal fluctuations.

TABLE 2.1 RELATION OF INDUSTRY PROFITS TO FRB INDEX*

	(a) Decline in sub-group production with 10% decline in FRB index	(b) Decline in profit margin with 10% decline in FRB index	(c) Decline in aggregate profits with 10% decline in FRB index†
Manufacturing	11%	12%	22%
Durable	13%	12%	23%
Automotive	17%	8%	24%
Furniture	13%	32%	41%
Iron and steel	14%	9%	22%
Lumber	20%	27%	42%
Non-ferrous metals	16%	12%	26%
Non-durable	5.4%	11%	16%
Apparel	7.6%	16%	22%
Chemicals	5.8%	8.5%	14%
Food	6.1%	7%	13%
Paper	7.0%	12%	18%
Textiles	7.6%	12%	19%

Decline measured from levels in the closing months of 1948.
* From Dean, *Managerial Economics*, p. 346.
† Column c = 1 − [(1 − col. a) × (1 − col. b)].

2. DEMAND ANALYSIS

Demand analysis has two main managerial purposes: (1) forecasting sales, and (2) manipulating demand. The sales forecast is the foundation for planning all phases of the company's operations, since purchasing commitments, production schedules, inventory plans, cash budgets, and capital expenditure programs all hinge on the short- and long-run view into the future. In an industry that is subject to wide seasonal swings in sales, there is an optimum production program that minimizes the total costs by balancing the costs (and risks) of inventory accumulation in slack seasons against the savings of larger lots and level production. In shooting for this operating program, forecasts of sales obviously play a basic role.

As yet, only a few firms take full advantage of demand analysis as a technique for formulating business-getting plans and policies. Sales forecasting is largely passive; it estimates external economic factors and predicts the resulting sales volume the firm can expect if it continues on its present course.

To use demand studies in an active rather than a passive way, management must recognize the degree to which sales are a result of advertising, price policy, product improvements, and marketing effort. An estimate of what will happen with no changes in policy is important, but this is only one of many alternative programs. Passive forecasts should be primarily a benchmark for estimating the consequences of other plans for adjusting prices, promotion, and/or products.

2.1 DEMAND THEORY

In order to shape an empirical analysis of demand that will answer specific questions, we should be familiar with various concepts of demand and know which concept is appropriate for each sort of management problem.

2.1.1 Demand functions. Economic theory of demand has concentrated on the relation between the price of a product and the volume sold, which is frequently called the demand schedule. However, price is just one of many factors affecting sales, and the demand schedule is a single part of the complete functional relation between sales and its determinants. Promotional outlays, product styling, national income, and competition affect sales as strongly or even more strongly than does price, and these variables all interact with one another in such a way that the simple price-sales relation or income-sales relation depends on the level of all other variables. Thus we theoretically have, in mathematical terms, demand functions in which several independent variables act jointly on the dependent variable, sales.

In empirical analysis, we never have sufficient data to establish complete demand functions, and the general practice is to go after important parts of the function—e.g., the income-sales relation —when other variables are reasonably steady. Which parts of the function are most important for a particular product depends on the type of product, type of buyer, and type of competition to be met. In general, however, buyers' income is the most important of the variables that are beyond management's control, and price and promotion are the most important controllable variables.

2.1.2 Producers' goods vs. consumers' goods. There are three general reasons for expecting distinctive demand behavior for producers' goods: (1) Buyers are professionals, and hence are more expert, price-wise, and sensitive to substitutes. (2) Their motives are more purely economic; products are bought, not for themselves alone, but for their profit prospects. (3) Their demand, being derived from demand for the end-product consumers' goods, fluctuates differently and generally more violently.

2.1.3 Durable goods vs. perishable goods. Durable products present more complicated problems of demand analysis than products that give a one-shot service, since they add an increment to

a stock of existing goods that dole out their services slowly over several years. It is therefore a common practice to segregate current demand for durables in terms of replacement of old products and expansion of the total stock.

The most important replacement determinant is the obsolescence rate, which governs the profitability of displacement. Physical deterioration is rarely a deciding factor in replacement of durable goods, since style, convenience, and income have come to play a dominant role in demand, even for producer goods.

A decision to buy a durable good for expansion is complicated by the need to guess about the future. It is necessary to estimate future maintenance and operating costs in relation to future income and other demands, future trade-in or salvage values, and whether prices will rise or fall if the purchase is postponed.

2.1.4 Derived demand vs. autonomous demand. When demand for a product is tied to the purchase of some parent product, its demand is called "derived." Sometimes the dependent product is a component part (e.g., demand for doors derived from demand for houses). Sometimes dependence comes from complementary consumption (e.g., pretzels from beer). Derived demand is generally supposed to have less sensitivity to price than autonomous demand.

The use of some products (e.g., television antennas) is so closely tied to the use of others that they have no distinctive demand determinants of their own. But fixed proportions are rare; more often there is substitution leeway in the proportions as well as more than one parent use. Crude-rubber demand, when related to the population of motor vehicles, shows both these characteristics.

As variability in the proportions and the number of uses increases, it becomes harder to tie demand down to parent products. For instance, small electric motors have no primary uses, but to analyze their demand in terms of their thousands of parent uses is impossibly tedious. The derived-demand approach facilitates forecasting when proportions of the two products are fairly stable and when there is a rigid time-lead in the parent product's demand.

2.1.5 Industry demand vs. company demand. Many management problems require analyses that distinguish industry demand from company demand and explore the relationship between them. For example, a projection of industry sales is usually an intermediate step in forecasting company sales; intelligent price leadership (and follower-ship too) is based on an understanding of the relation of the company demand to that of competing firms.

An industry-demand schedule represents the relation of the price of the product to the quantity that will be bought from all firms. It has a clear meaning when the products of the various firms are close substitutes, when they differ markedly from those of bordering industries, and when they have a well-defined price level. When, on the other hand, there is considerable product differentiation within the industry, and when there is substitute competition with other industries, the concept of an industry-demand schedule becomes nebulous. Adding Cadillacs and Austins and averaging their prices does not produce a very meaningful demand schedule.

The conceptual distinction between industry demand and company demand is most useful when the boundaries of the industry are clearly definable in terms of a gap in the chain of substitutes (i.e., products that differ sharply in terms of substitutability from those of other industries), and when rival firms are large enough and similar enough to plan in terms of market share. Empirical research can then be framed in terms of price spreads or ratios over rivals, and of the effect of these price differentials upon market share.

As an illustration, estimates have been made of the sensitivity of gasoline market shares to changes in price differentials among brands. Narrowing or widening the differentials between the branded product of the price leader and the local private brand of the cut-rate distributor has a prompt effect on retail patronage, and the sensitivity of market share ap-

parently rises sharply when the spread widens beyond a critical point. Similar market-share analyses can be carried out for other demand determinants, such as consumer income and advertising.

"Market-share" concepts of demand are most usable in mature, well-defined industries whose products are relatively homogeneous—e.g., steel or cement. In this setting, market-share objectives often are dominantly defensive. Emphasis is put on the first step—forecasting industry sales. The second step—planning marketing strategy to affect market share—is, for established firms, largely a matter of keeping abreast of competitive developments, e.g., overtaking product innovators, meeting price cutters, and countering advertising aggressors.

2.1.6 Short-run demand vs. long-run demand. A distinction between long-run and short-run demand functions is useful for many problems. Short-run demand refers to existing demand with its immediate reaction to price changes, income fluctuation, and so forth. Long-run demand is that which will ultimately exist as a result of the changes in pricing, promotion, or product improvement, after enough time has been allowed to let the market adjust itself to the new situation. Factors that cause these differences between short-run and long-run demand fall in two categories: (1) cultural lags in information and experience, and (2) capital investments required of buyers to shift consumption patterns.

Lags in long-run response of demand last until consumers get acquainted with the uses of a product through experience and research. Illustrations of the investment needed to exploit price cuts are the large refrigerators and freezers required for mass consumption of frozen foods and the oilburners needed to heat houses by oil.

2.1.7 Demand fluctuations vs. long-run trends. The difference between forecasting year-to-year changes and forecasting underlying trends is analogous to that between business cycles and secular economic development. The external factors that are important for cyclical forecasts are different from trend projections. In year-to-year changes, much of the setting stays constant—competitive structure, market position, quality, and sometimes even prices (relative to substitutes and competitors, if not absolutely). The problem can then be narrowed down to the relation between sales pulsations and a few strategic variables, such as income, business activity, and competitive price differentials. For the long trend, in contrast, everything is fluid, and the effects of year-to-year determinants are buried by basic changes in the framework—e.g., shifts in taste, technology, and way of life in a laboristic, urban, welfare state.

2.1.8 Total market vs. market segments. The comprehensiveness of the demand problem sets the framework for analysis. Some problems, such as sales forecasting, call for an analysis that includes the total market. Other problems—notably in pricing, promotion, and distribution—call for analyses of separate market segments that have homogeneous demand characteristics.

2.2 METHODS FOR FORECASTING DEMAND

Most sales forecasting is concerned only with short-run projections for established products. Long-range predictions for such products are seldom made, partly because the projections are precarious, but mainly because long-term decisions that require such forecasts arise only infrequently. New products present an entirely different problem. The question here is whether to make the big initial investment in the first place. For this decision, the long-range view is more important than the effects of next year's phase of the business cycle.

Demand forecasting for established products can usually be worked into a routine procedure, with information drawn from the existing markets and from past behavior of sales. Since most of the determinants of demand are expected to change very little through the forecast period, the analysis can often be simplified and concentrated on a few strategic short-run variables.

Forecasts for new products, on the other hand, are necessarily custom-built jobs that take more ingenuity and expense. Since the product has never been sold before, there is no empirical evidence of a base demand that can be used as a foundation for refined estimates, nor is there a structure of market prices for the product and its substitutes that can be projected into the future.

2.2.1 Forecasting sales of established products. The most direct method of estimating sales in the near future is to ask customers what they are planning to buy. This is most useful when sales are to industrial producers, although this method simply puts the forecasting burden on the customer.

A more subtle, though devious, attack can be made by asking the people who are likely to know what customers will buy. Many companies get their basic forecasts directly from their salesmen, on the theory that the grass-roots contact man has the most intimate "feel" of the market. Jobbers, wholesalers, and retailers are polled for the same reason. In this kind of forecast, the total is generally built up by adding the individual salesmen's projections, then scaling down for errors of optimism by pooling the collective wisdom of top executives in second guessing and consolidating results.

A third forecasting method is to use statistical methods for analyzing time series that break up the past behavior of sales into several components, such as a long-term exponential trend, a group of sine curves for business cycle movements, and a seasonal pattern. This method is never very firm, because of basic changes in institutions, motivations, and risks that continuously take place. But in a growing economy, good long-range forecasting results have been obtained for some products (e.g., electric power) by projecting the trend alone.

A fourth method of forecasting is what statisticians call correlation analysis. To work a least-squares correlation, the analyst looks over historical data on market conditions to find the factors (other than time) that he thinks influence sales and for which data are available over a period with wide fluctuations. His next step is usually to test the closeness of the relationship of each candidate factor to sales and to other factors; in effect, he makes a selection of independent variables. He then chooses a plausible algebraic relation (e.g., linear, quadratic, logarithmic, etc.) between sales and these independent variables. The analyst then grinds the data through a calculating machine and produces the most probable values for the coefficients in the equation.

This set of numerical relationships may be a valuable tool in sales forecasting. It channels estimates toward most probable values, based on the continuation of past relationships with "causal" factors that are measurable. The eternal quest is for a lucky lag function, one with sales in close relation to something that happened, say, six months before. When, instead, sales are related to a simultaneous development—e.g., the Federal Reserve Board Index of Industrial Production—then the forecasting problem is to map the future of this independent variable rather than sales themselves. Sometimes the independent factor is inherently more easily forecasted than the sales in question—e.g., population or birth-rates.

2.2.2 Forecasting demand for new products. Methods of forecasting demand for new products are quite different from those for established products. Forecasting methods have to be tailored to the particular product. Possible approaches can be classified as follows:

(1) Project the demand for the new product as an outgrowth and evolution of an existing old product. (2) Analyze the new product as a substitute for some existing product or service. (3) Estimate the rate of growth and the ultimate level of demand for the new product on the basis of the pattern of growth of established products. (4) Estimate demand by making direct inquiries to the ultimate purchasers, then blow up the sample to full scale. (5) Offer the new product for sale in a sample market—e.g., by direct mail or through one chain store. (6) Survey consumers' reactions to a new product indirectly through the eyes of specialized dealers who are supposedly

informed about consumers' needs and alternative opportunities.

2.3 PRICE RELATIONS

Demand analysis designed to highlight the role of price as a controlling factor is useful for forecasting, but its major role is in market management: pricing, advertising, distribution, and product design. A close analysis of price relations may reveal unseen areas for positive pricing policy. Nevertheless, empirical investigations of the effect of price on a manufacturer's sales remain a relatively untouched field of demand analysis. This is one reason why many companies do not have independent price policies but, rather, follow the industry leader or use cost criteria for pricing. Price relations are extremely difficult to analyze for manufactured products: the frequency and range of price variation are inadequate. A price change is generally felt only after a long gestation period, and its effects are buried in the shifts of the over-all economy during that period. Since price relations depend on the closeness of substitutes and the behavior of their prices as well, the price relations for an industry are different from those for a company.

A promising method for studying price relations is the controlled experiment. There are various forms of experimentation with prices in the market that can reveal an approximate price-sales schedule over the range of possible prices. Other methods, including consumer questionnaires, engineering estimates, and correlation analysis, can, under appropriate conditions, produce usable estimates. For agricultural commodities, correlation analysis of the relation between short-run behavior of sales and short-run changes in prices has been widely used.

2.4 INCOME RELATIONS

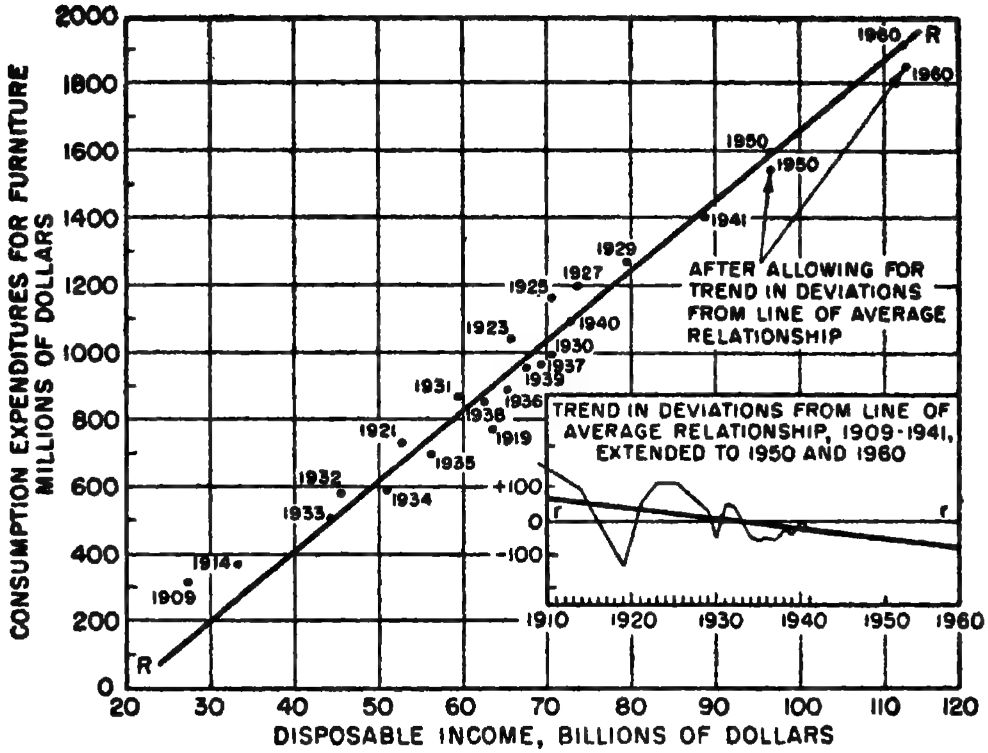
The relation of changes in demand to changes in buyers' income is basic for short-run forecasting. It has been the subject of much statistical study, particularly in terms of total national income or disposable personal income. Similar analyses of corporate income (profits) in relation to business investment have produced significant correlations.

The net relation of sales to, say, national income is not simple, however, since it depends upon the underlying relations of the incomes of the particular group of buyers to the national aggregate. For example, if a function is fitted statistically to historical data for hay-baler sales and national income, the curve is valid for the future only if hay-farmers' income fluctuations either conform rigidly to the national pattern or maintain the same relationship to national income as in the past. This problem frequently arises when broad aggregates are used statistically, since such aggregates usually include much more than is relevant to the analysis of a single product's demand.

An illustration of a simple method for determining income relations is given in Fig. 2.3, which shows such a function for household appliances. The straight line in this chart is drawn free-hand, using the data for 1909-1940, and extrapolated to full-employment income levels that were expected for 1950 and 1960 to make an estimate of potential appliance sales for those years Deviations from the straight-line function show a distinct upward trend when plotted against time; if the trend is taken into account, the estimates are raised substantially, as shown.

2.5 MULTIPLE RELATIONS

Analysis of demand in terms of a single controlling factor has only limited value, since the effect of price or income on demand, though perhaps dominant, is measurably qualified by other variables such as competitors' prices or changes in income. The natural route to a general demand function is therefore multiple correlation analysis, where we can use several independent variables and



Frederic Dewhurst and Associates, *America's Needs and Resources* (New York: Twentieth Century Fund, 1947), p. 728, reprinted in Dean, *Managerial Economics*, p. 198.

FIG. **2.3** RELATION BETWEEN DISPOSABLE INCOME AND CONSUMPTION EXPENDITURES FOR FURNITURE—1909-1941, EXTENDED TO 1950 AND 1960.

get some idea of the relative influence of each on demand.

Figure 2.4 illustrates this technique as applied to furniture demand.

Of several functional forms that were tried, the best turned out to be a hyperbola:

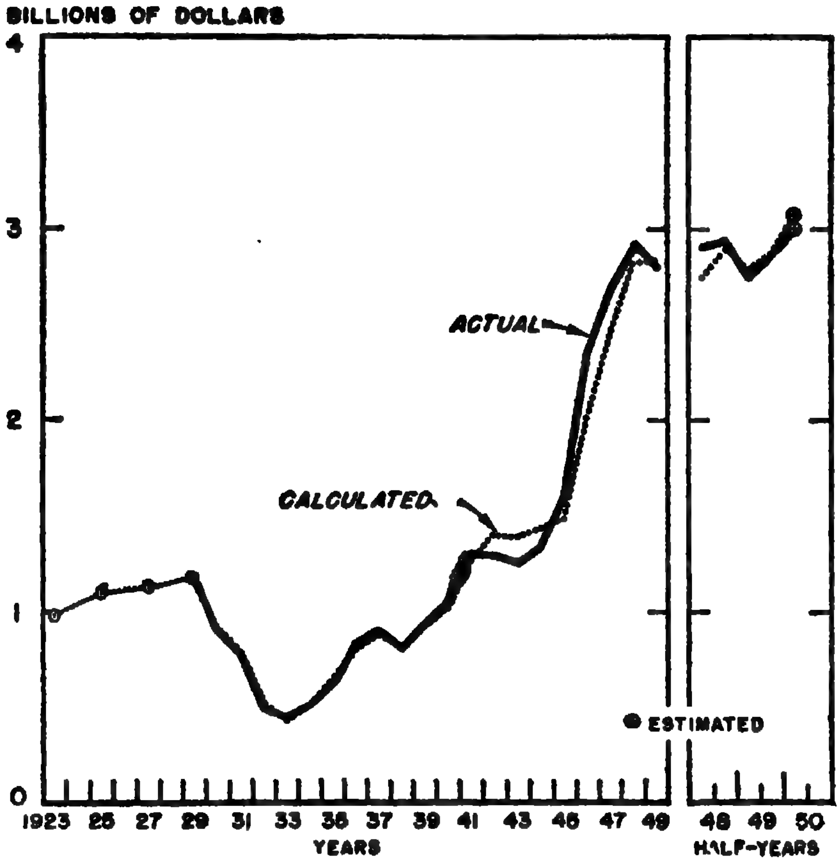
$$F = .0036\, Y^{1.08} R^{0.16} P^{-0.48}$$

where F equals furniture expenditures per household, Y equals disposable personal income per household, R equals value of private residential construction per household, and P equals ratio of the furniture price index to the Consumer Price Index. The multiple correlation coefficient for this function was .996, which means that for the 18 years used in the computation, there was virtually no deviation between actual and calculated furniture sales. The degree of fit to postwar years, the real test of the value of the equation, is surprisingly close.

In using this statistical approach, the important problem is to find a few efficient causal factors, rather than to compile a catalog of influences on sales. Efficient indicators are found not only by insight into demand determinants, but by adaptation of statistical analysis to the problem and by experimentation with different functional relations. For instance, the durability of a demand function is often enhanced by converting dollar values into physical units and occasionally by using a time lag between variables. When such refinements are not feasible, flexibility is a more economical substitute for durability than is elaborateness.

3. COST

Business decisions are based upon plans for the future and require choices among rival plans. In making these choices, estimates are needed of the



Dean, *Managerial Economics*, p. 212.

FIG. 2.4 PERSONAL CONSUMPTION EXPENDITURES FOR FURNITURE: ACTUAL AND CALCULATED. (SOURCE: SURVEY OF CURRENT BUSINESS, MAY 1950, P. 8.)

effect of each alternative plan upon future expenses and revenues, and cost estimates must be tailored to the economic characteristics of the choices. It should be recognized at once that the only costs that matter for business decisions are future costs; "actual" costs—i.e., current or historical costs—are useful solely as a benchmark for estimating the costs that will result from particular decisions.

What does it take to get good estimates of these decision-making costs? The first requisite is a precise picture of the alternative programs involved in the choice. An explicit definition of the differences among alternatives usually requires economic analysis of the situation. A second requirement is an understanding of different cost concepts, in order to select the one that is most relevant. In operating a modern multiple-product enterprise, the situations requiring decisions are so varied not only among themselves, but in the character of the alternatives available, that many different concepts of cost are needed for significant comparison of the alternative plans. The third requisite is flexible classification of the accounting records on several alternative bases. Since decision-making costs require classifications according to rival operating plans, multiple classifications are a desirable informational foundation for such cost estimates. A fourth requisite is ingenuity and skill in quantitative analysis, since typically the desired cost conjectures can be improved by statistical analysis of accounting data.

Decision-making costs can be found from traditional accounting records only by reclassifications, deletions, additions, recombinations of elements, and repricing of input factors in the process of shap-

ing the cost conjectures to fit the concept of cost relevant for the management planning choice. Traditional accounting, because of the need for verifiable data to fulfill its financial reporting function, uses "original cost"—i.e., historical prices of input factors—so that costs do not (with a few exceptions, such as inventory valuation during inflation) reflect changes in price levels or managerial mistakes in investment. Traditional accounts are classified primarily on the basis of the object of expenditure, which is handy for verification. When a classification by function (process or department) is superimposed, it also is generally a formalized, unvarying classification, and the assumption is usually made that the original outlay can be spread among functions proportionately to one or several allocation bases, such as direct labor hours, square feet of space, and the like.

Records of historical outlays, based upon these rigid classifications and formal proportionalities, need to be drastically reworked for decisions about the future. Classification should depend upon the nature of the rival programs being considered, and therefore should change from problem to problem.

Valuation as well as classification depends on the purpose of analysis and differs with the economic characteristics of alternative programs. A single piece of equipment will have different values in terms of its disposal price, replacement cost, value in its present job, and value in alternative jobs. The only values that are irrelevant for all decisions on what to do with a specific asset are its original cost and its book value.

Control and appraisal of executive performance require an approach to cost analysis that is essentially different from studies to aid decision-making. For managerial control, costs must be classified according to areas of executive responsibility, and according to the degree of authority over expense delegated to the executive. Once one of the alternative plans is chosen, responsibility for carrying it out in an acceptable manner is assigned, and expenses must be reclassified in a manner that will measure how the performance of each executive compares with some standard or budget. Thus the basic classification by objects of expenditure required for pecuniary history and financial reports must be set up to enable easy reclassification on a basis that parallels the structure of managerial organization.

3.1 COST CONCEPTS

The kind of cost concept to be used in a particular situation depends upon the business decision to be made. Hence an understanding of the meaning of various concepts is essential for clear business thinking. Several alternative bases of classifying costs and the relevance of each for different kinds of problems are discussed below.

Although it may be difficult, workable approximations of these concepts of cost can be developed, given, first, a clear understanding of the management problem and of the concept of cost that is relevant for it; second, familiarity with the business and its records; and, third, ingenuity and boldness. Most of the raw materials for making these special cost estimates are found in the accounting and statistical records of the company, though sometimes they need to be supplemented by special data.

Different combinations of cost ingredients are appropriate for various kinds of management problems. Disparities occur from deletions, from additions, from recombinations of elements, from price-level adjustments, and from the introduction of measurements that do not appear anywhere in the accounting records.

3.1.1 Opportunity vs. outlay costs. A distinction can be drawn between outlay costs and opportunity costs on the basis of the nature of the sacrifice. Since outlay costs involve financial expenditure at some time, they are recorded in the books of account. Opportunity costs take the form of profits from alternative ventures that are foregone when limited facilities are used for a particular purpose. Since they represent only sacrificed alterna-

tives, they are never recorded as such in the financial accounts.

Opportunity cost is the cost concept to use when the supply of input factors is strictly limited. Such rigid supply may occur for technical reasons, e.g., the limited number of television channels available in a single locality; for social reasons, e.g., wartime rationing; for private reasons, such as lack of ready cash; or because the problem is too short-run to adapt facilities to their most profitable long-run relation to the job. In business problems the message of opportunity costs is that it is dangerous to confine cost knowledge to what the firm is doing. What the firm is not doing but could do is frequently the critical cost consideration that it is perilous but easy to ignore. Under conditions of capital rationing, for example, the cost of acquiring a $100,000 gasoline station in New York City is not usually the interest that would have to be paid on the borrowed money but, rather, the profits or cost savings that could have been achieved if the $100,000 had been invested in four suburban gasoline stations, or in pipelines or refinery facilities.

3.1.2 Past vs. future cost. Most of the important managerial uses to which cost information is put actually require forecasts of future cost, rather than "actual costs," i.e., unadjusted records of past cost. An examination of some of the major managerial uses to which cost information is put reveals the universality of this principle. Among these uses are: expense control, projection of future income statements, appraisal of capital expenditures, decisions on new products and on expansion programs, and pricing. When historical costs are used, the assumption is made that unvarnished cost history is the best available estimate of probable future costs under the situations involved in the decision.

The fact that the future is always uncertain does not detract from the necessity for making explicit forecasts of future costs. We can usually make a more accurate projection than historical costs, which rarely represent the best guess that can be made concerning the future.

3.1.3 Short-run vs. long-run costs. The distinction between short-run and long-run cost behavior is basic in economic theory. Roughly, short-run costs are associated with variation in the utilization of fixed plant or other facilities, whereas long-run cost behavior encompasses changes in the size and kind of plant. The distinction is based upon the degree of adaptation of all input factors to rate and type of output. When there is perfect flexibility in the size of plant, labor force, executive talent, and so forth, long-run costs are identical with short-run costs. Anything short of perfect flexibility produces cost behavior that can be changed, given time and investment resources. Such alterable costs are short run. The conventional dichotomy of long-run versus short-run cost curves needs to be expanded in economic theory to envision a whole family of cost curves that differ in degree of adaptation, so that the conventional long-run cost curve is the limiting case of perfect adaptation. In the real world, adjustments to higher output, new materials, or new product designs typically take a variety of forms that fall short of the perfect adaptation of the long-run cost curves. They progress gradually by widening a succession of bottlenecks rather than by adding an entire balanced unit.

3.1.4 Variable vs. constant cost. Variable costs are distinguished from constant costs on the basis of the degree to which they vary in total with changes in rate of output. Which cost items are fixed and which variable depends on the degree of adaptation of costs to output rate, i.e., the degree to which the adjustment is short-run as opposed to long-run. The distinction also depends on the size and the suddenness of the change in output, and on the amount of pressure put on management to increase efficiency and to defer postponable expenditures.

The distinction between variable and constant costs is important in forecasting the effect of short-run changes in volume upon costs and profits. The break-even chart illustrates this application in predicting profits; the flexible budget illustrates an application to control of costs

by setting standards that are adjusted for volume changes.

3.1.5 Traceable vs. common cost. A traceable cost is one that can be identified easily and indisputably with a unit of operation, e.g., a product, a department, or a process. In accounting terminology, direct costs are distinguished from indirect costs on the basis of traceability to different products. Common costs are costs that are not traceable to individual final products, or to plant, department, and operation.

Traceability of costs becomes important when multiple products that incur common cost differ considerably in production or marketing processes, and when cost has significance in decisions on adding or subtracting from a product line, product pricing, or product merchandising. It is not necessary that costs be traceable all the way to the product for this distinction to be useful for management. The degree of traceability varies from cost to cost, some costs being traceable as far down as divisions, others down to departments, and others down to cost centers.

3.1.6 Out-of-pocket vs. book cost. Out-of-pocket costs refer to costs that involve current payments to outsiders as opposed to book costs, such as depreciation, that do not require current cash expenditures. Not all out-of-pocket costs are variable—e.g., the night watchman's salary. Not all out-of-pocket costs are traceable—e.g., the electric power bill. Conversely, book costs are in some instances variable—e.g., depletion of ore or oil—and in some instances are readily traceable and hence a part of direct costs. The distinction primarily affects the firm's cash position, but it is also significant for other than liquidity decisions.

3.1.7 Incremental costs vs. sunk cost. Incremental costs are the change in total costs resulting from a change in the level or nature of activity. They can refer to any kind of change: adding a new product, changing distribution channels, adding new machinery. Sunk costs are the costs that are not altered by the change in question. Most business decisions require cost estimates that are essentially incremental, and costs that are not altered by the contemplated change are sunk and irrelevant.

Incremental costs are not necessarily variable, traceable, or cash costs. In many short-run problems, the most important incremental cost is the foregone opportunity of using limited facilities in their present work rather than shifting them to a new activity. Similarly, sunk costs can be cash costs (e.g., the president's salary); they can be variable (e.g., when the change in question is of customers rather than products); and they can be traceable.

3.1.8 Controllable vs. non-controllable cost. The distinction between controllable and non-controllable costs depends upon the level of management. Some costs are not controllable at the shop level since they depend on decisions upstairs, but at some level all costs come into the discretionary area of some executive. The controllability distinction is primarily useful for expense and efficiency control, since budgets can be set up that correspond to areas of managerial responsibility, as discussed in Art. 1, profits.

From the foregoing classification, it is clear that cost is a relative matter. What is cost depends upon what sacrifices are really produced by a particular business decision. These different cost concepts do not necessarily correspond to any accounting category. It is better to use a rough approximation of the concept of cost that is correct for a particular decision than to have an accurate estimate of an irrelevant concept. The unsophisticated executive is in danger of taking the easier course of using conventional accounting costs as though they were appropriate for all purposes. Instead, it is better to modify reported costs as necessary to make the best possible guess at the concept theoretically relevant for each decision.

3.2 COST AND OUTPUT RATE

Generally, in the short run a functional relation exists between cost and a set of independent variables, which

TABLE 2.2 CLASSIFICATION OF COST DISTINCTIONS*

Dichotomy		Basis of distinction
Opportunity Costs	Outlay Costs	Nature of the Sacrifice
Past Costs	Future Costs	Degree of Anticipation
Short-Run Costs	Long-Run Costs	Degree of Adaptation to Present Output
Variable Costs	Constant Costs	Degree of Variation with Output Rate
Traceable Costs	Common Costs	Traceability to Unit of Operations
Out-of-Pocket Costs	Book Costs	Immediacy of Expenditure
Incremental Costs	Sunk Costs	Relation to Added Activity
Escapable Costs	Unavoidable Costs	Relation to Retrenchment
Controllable Costs	Non-Controllable Costs	Controllability
Replacement Costs	Historical Costs	Timing of Valuation ·

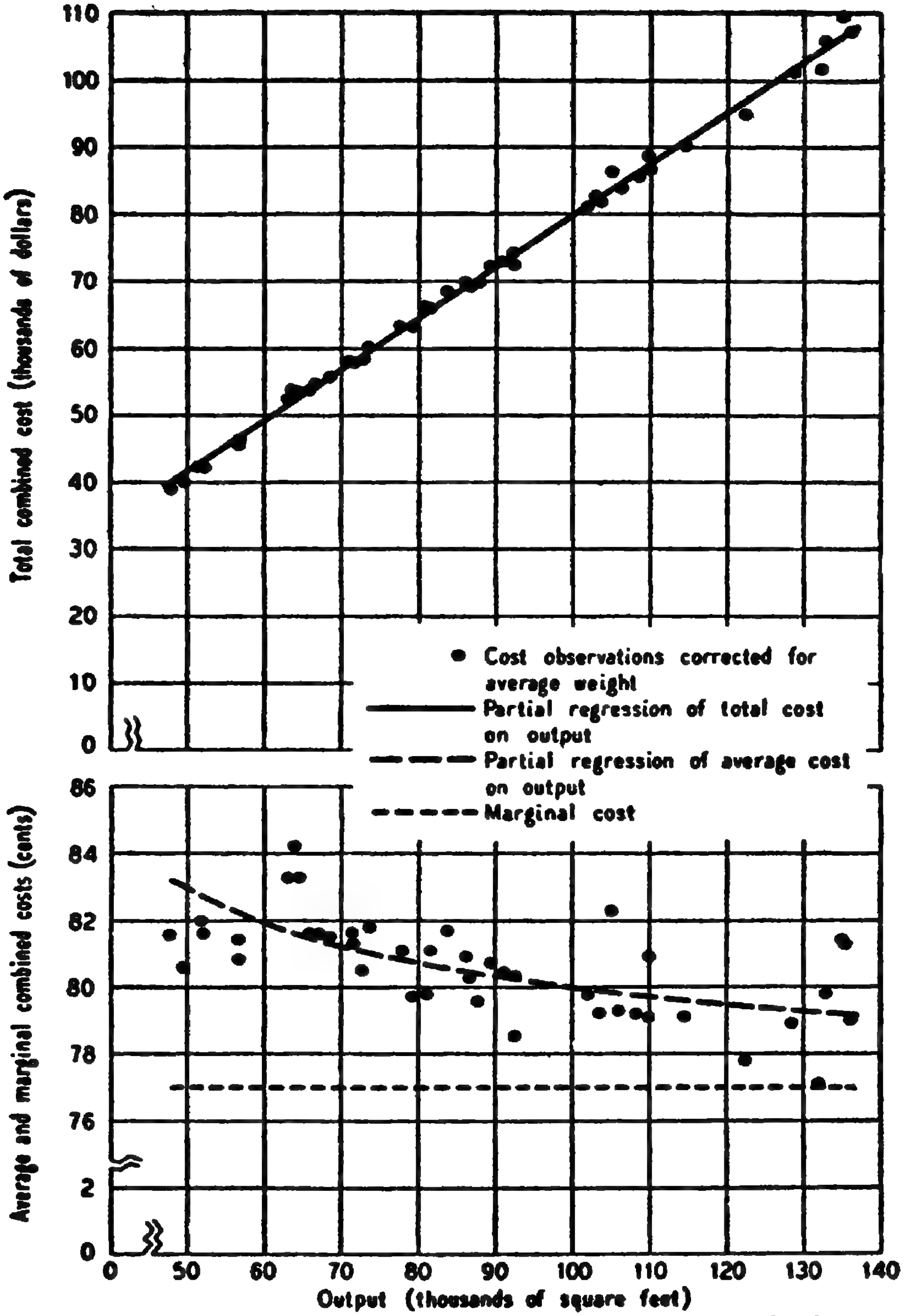
* From Dean, *Managerial Economics*, p. 271.

may include, for example, volume of production, size of production lot, prices of input services, and variety of output. The independent variables will be different for each type of manufacturing operation, although in general the most important variable is rate of output. The independent variables are considered to determine cost behavior.

The output relation is the most important to study because it is subject to faster and more frequent changes. The characteristics of the fixed equipment play a dominant role in the determination of a plant's pattern of short-run cost behavior—i.e., the shape of the relation between total cost and rate of output. The critical characteristic for this purpose is the degree of segmentation possible in the plant, that is, its potentiality of varying the rate of output flow without changing the proportions of variable inputs to fixed equipment in use Segmentation in this sense refers to the technical nature of the fixed equipment that permits a wide range of choice in the machine-hours used per week.

The point where a plant falls on this segmentation scale depends on the technical nature of the equipment, the success of managerial efforts to segmentize, and the nature of the labor contract. Three sources of segmentation can be distinguished. The first is physical divisibility, where fixed equipment consists of a large number of homogeneous units. An example of this is a hosiery mill where the knitting of stocking legs is done on many nearly identical knitting machines. It is possible, secondly, to introduce segmentation by varying the number and hours of the shifts per period that the fixed equipment is employed. Thirdly, if the technical nature of the fixed plant is such that it can be used at varying speeds, "speed" segmentation can be obtained by operating machines at faster or slower rates. In many industries the development of plants that can produce a variety of products in a wide range of proportions, and operate efficiently at many rates of output, have brought about much time, speed, and unit segmentation.

3.2.1 Different approaches to determination of cost functions. For several kinds of management problems it is desirable to find an empirical approximation of short-run cost functions. Empiri-



Dean, *Relation of Cost to Output for a Leather Belt Shop* (National Bureau of Economic Research, 1941), p. 27, reprinted in Dean, *Managerial Economics*, p. 293.

FIG. **2.5** PARTIAL REGRESSIONS OF TOTAL, AVERAGE, AND MARGINAL COMBINED COST ON OUTPUT: LEATHER BELT SHOP.

cal functions are necessarily approximate, since they cannot include every kind of short-run cost factor, nor can they find the exact relation of cost to the factors used.

There are several approaches to an estimate of cost function: (1) Classification of accounts into fixed, variable, semi-variable, on the basis of judgment and inspection. (2) Estimation of the relationships of cost-output on the basis of engineering conjectures. (3) Determination of the cost function and the degree of output variation by statistical analysis.

These three approaches are not always mutually exclusive. Often it is desirable to use two or more to supplement each other. Nevertheless, it is usually desirable to try to determine at the outset which of the three should receive greatest emphasis.

Statistical approach. When conditions are appropriate for its use, the statistical approach is likely to produce more reliable results than the other methods. In essence, it uses multiple correlation analysis to find a functional relation between changes in costs and the important cost determinants, such as output rate, lot size, output fluctuations, and so forth. (See Art. 5.8, Section 13.)

The power of statistical analysis lies in its ability to pick out the fixed cost elements in each cost component, such as direct labor of fuel consumption, and to show whether costs vary with changes in particular cost determinants.

Fig. 2.5 presents one finding of a statistical cost study.
The technique has been used here to isolate the relation between output and cost when all other cost determinants are held constant at particular levels. One never finds such constancy of "other" cost determinants in empirical series of cost observations. The constancy shown here is rather one of the products of the statistical method, a highly useful product where a management problem relates to changes in a single cost determinant.

Accounting approach. The accounting approach is usually aimed at finding only the relation between output levels and costs. The method consists of classifying each cost item by inspection into one of three categories: (1) fixed, (2) variable, and (3) semi-variable. Fixed costs are supposed to be the same (in monthly total) regardless of output rate; costs classed as variable are assumed to change proportionally with output; and semi-variable costs are sometimes assigned roughly some proportion of variability and sometimes further analyzed into fixed and variable components.

This method is the simplest and least expensive of the three, since the analysis is based chiefly on inspection and experience. It tends to give an oversimplified model of cost behavior and should be supplemented by graphic statistical analysis as a test of recent patterns of cost variability.

Engineering approach. In essence, the engineering method consists of systematic conjectures about what cost behavior ought to be in the future on the basis of what is known about the rated capacity of equipment, modified by experience with man-power requisites and efficiency factors, and with past cost behavior. Hence, it depends upon knowledge of physical relationships supplemented by pooled judgments of practical operators. It should, and usually does, make use of whatever analyses of historical cost behavior are appropriate and available, as a means of improving the judgment. Typically, the engineering estimate is built up in terms of physical units—i.e., man-hours, pounds of material, and so forth—and is converted into dollars at current or prospective cost prices. The cost estimates are usually developed at a series of peg points that cover the contemplated or potential output range.

The engineering approach is the only feasible method when the inadequacy of experience and records provides little systematic historical basis for estimating cost behavior. The approach is also desirable when it is necessary to estimate the effect of major changes of technology or plant size upon cost behavior over a familiar or unfamiliar output range.

3.3 COST AND SIZE OF PLANT

In the studies of short-run cost behavior discussed in Art. 3.2, plant size was approximately constant. We now turn to the long-run problem of finding empirically what effect varying the size of plants has upon cost.

To clarify the measurement problem, it is desirable to distinguish plant size from two other phases of size that sometimes confuse the issue: size of firm, and depth of plant. Size of plant is different from size of firm, even when there is only one plant. The firm encompasses several economic functions in addition to production. Each of these operations usually has a different cost-size relationship and a different optimum size. Big companies find a practical solution for this disparity in having units that differ in size for each economic function—e.g., 60,000-barrel refineries and 1,000-gallon gas stations. Despite oceans of speculation, little is really known about the relation of size of firm either to cost or to more subtle and relevant measures of over-all economic efficiency, such as profitability. Our problem here is simply to find how cost varies with the size of plant for a particular function, such as retailing shoes or generating electricity.

The problem of size of plant must also be distinguished from depth of plant. Plant depth is a different dimension of "size" that is analogous to the degree of vertical integration for the firm. A pure assembly plant is not comparable to a plant that manufactures its own parts and subassemblies. Such differences in plant depth confuse the conception of the relation of plant size to cost or obscure its measurement.

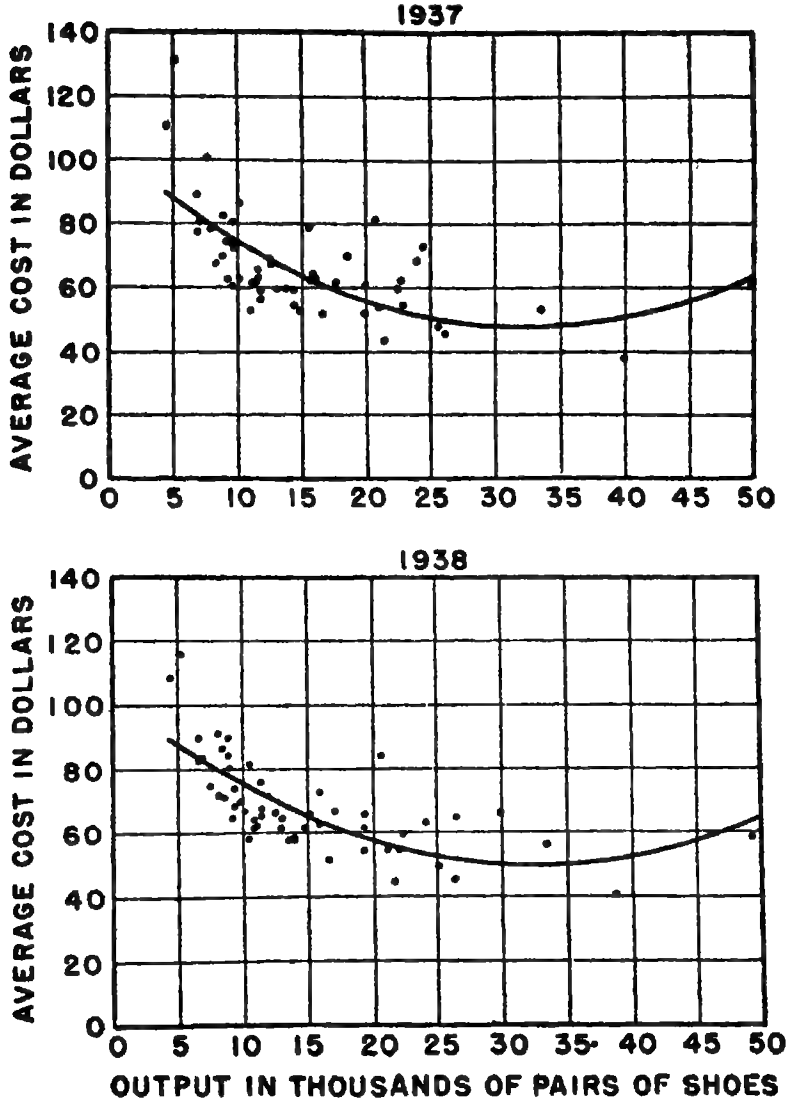
Four approaches to the problem of cost and size of plant merit consideration: (1) Analysis of changes in actual cost that accompanied the growth of a single plant over a period of time. (2) Analysis of differences in actual cost of plants of different sizes operated by separate firms and observed at the same time. (3) Engineering estimates of the alternative cost where the same technology of manufacturing is used in plants of different sizes. (See Section 3, Engineering Economy.) (4) Analysis of differences in the actual costs of different-sized plants operated by one corporation.

The first approach encounters insuperable difficulties in correcting the data for changes in products, technology, and management, unless the firm displays very little technical advance during its growth. Successive observations of the firm as it adapts itself are likely to represent an expansion path that traces only growth in number of plants operated and seldom large-scale increases in plant size. Problems also arise in rectifying cost data for changes in prices, and for differences in valuation and in accounting procedures.

The second approach—simultaneous observations of plants that differ in size and ownership—encounters comparable difficulties of appraising differences in products, techniques, accounting methods, valuation bases, price levels, and managerial effectiveness. Even for so homogeneous a product as electric power, there are variations in daily load patterns, age of plant, and many other factors that make cost comparisons all but meaningless for measuring the economies of large-scale plants.

The third method—engineering conjectures of costs of plants of different size—is the only one that has wide usage in the business community. However, the question always arises of how adequately such estimates take account of all operating circumstances. Recent experiments with pulverizing big plants and operating several smaller units have indicated that imponderables missed by engineering estimates are significant. Gains from the standpoint of employee morale and management efficiency seem to have offset economies of specialization.

The fourth method is promising for some types of problems. If a company has a large number of plants carrying on similar activities—for instance, a chain of grocery stores or warehouses—the question of the minimum-cost size of such plants inevitably arises. If the plants have uniform accounting systems



Dean, *Long-Run Behavior of Costs in a Chain of Shoe Stores* (Chicago: University of Chicago Press, 1942), p. 25, reprinted in Dean, *Managerial Economics*, p. 313.

FIG. **2.6** AVERAGE-COST FUNCTION FOR SHOE STORE CHAIN.

and uniform management policies, this problem is susceptible to a statistical analysis similar to the methods discussed in the previous section. Figure 2.6 shows the results of such a study for a retail store chain.

3.4 COSTS OF MULTIPLE PRODUCTS

Determination of the costs of individual articles produced and sold in multiple-product operations is of great practical importance for some problems. For example, it can be used to guide birth and death decisions that affect product line, to influence product modification and redesigning, to select the most appropriate system of price differentials among members of an existing product line, and to indicate opportunities and limits for non-price competition by revealing the incremental profits of different products.

The individual product costs needed are the increments that will occur if and when the change in question occurs—i.e., the costs that are different if the decision goes one way rather than the other. These incremental and opportunity costs needed for decision-making have no necessary relation to the prod-

uct costs obtained by conventional cost accounting. The conventional "full costs" are built from records of historical outlays and from necessarily arbitrary allocations of overheads, many of which are unaffected by (and therefore irrelevant to) the particular decision.

Some costs are traceable to individual products (e.g., purchased parts and components), while other costs are common to several products (i.e., they are not easily identified with a single product). For example, the cost of the factory building is common to all the types of products made there. The problem of product-costing arises in identifying parts of common costs with particular products.

Some common costs are unaffected by the kind of change that is up for decision. Common costs that are fixed do not need to be allocated, since they are irrelevant for any decision for which they are constant. It is the common costs that vary with the decision that must be allocated to individual products.

Some decisions involve such a major overhaul of the cost structure that special cost studies are needed to determine the incremental costs. But the occasions for such decisions are quite rare. More frequent are problems that are closely related to variations in rate of output of particular products. For these decisions short-run variable costs are most important. Hence special attention needs to be given the allocation of variable common costs.

3.4.1 Jointness of products. For product-costing it is desirable to distinguish two broad categories of common products: joint products and alternative products. When an increase in the production of one product causes an increase in the output of another product, then the products and their costs are traditionally defined as joint. In contrast, when an increase in the output of a product is accompanied by a reduction in the output of other products, the products may be called alternative. Slag and steel are joint products, but steel rails and steel bars are alternative products.

In principle, two joint-cost situations can be distinguished. First, when the proportions of the end products can be varied; second, when these proportions are fixed. When proportions are fixed, separate product costs are indeterminate. There is not even much point in contemplating the separate costs of bringing hams and shoulders to the slaughter-house, since each unavoidably accompanies the other. When one product is much less important than the other, it may be called a by-product, a gratuitous use of a waste material, but there is no real distinction between joint products and by-products. Where the march of technology is rapid, as in chemistry, by-products soon become joint products and may even take on senior status.

For joint products of variable proportions, cost problems relate commonly to the incremental effect of an increase in output rate to meet new demand for one of the joint products. Such an increase involves higher output for all the products and may therefore cause a reduction in prices of joint products in order to get rid of them—e.g., more slag from increased output of steel. Thus the added revenue from one joint product must cover not only the added cost of the whole product package, but also any loss of revenue from lowered prices of the other joint products as well.

In the case of common costs that are not joint between two products, increasing the output of one product is either unassociated with an increase in the output of the other, or requires a sacrifice or reduction of the output of the other. In the first instance, the separate incremental costs are, at least in principle, determinant; in the second case, where sacrificed production of other products is involved, the concept of opportunity costs is frequently the most important. For example, the principal cost of canning tomatoes may be the foregone opportunity to pack tomato juice.

3.4.2 Petroleum refining—an illustration. An illustration from home-heating fuel oil may help to point up the foregoing analysis.

Crude oil yields a mixture of joint and alternative products, in which, as a result of modern refinery processes—catalytic cracking and polymerization—the range of practical variation in proportions of gasoline and fuel oil is rather wide. Given this variability, the refiner's problem is to determine the real costs that will be incurred by a decision to increase the output of fuel oil without changing gasoline production.

The most satisfactory way to estimate the cost of heating oil for this management decision is its gasoline opportunity cost. The cost of heating oil is the foregone gains that could have been realized by converting the oil into gasoline, which is usually the most important product. Gasoline is the important product, because it is the one that justifies the refinery investment. It is the big-volume, high-margin product, the demand for which is inelastic, largely because there is little substitute competition. Hence there is also less risk of losing the market than there is of losing the market for heating oil. Thus costing heating oil on the basis of gasoline conversion value measures almost directly the minimum price at which it would be better to convert into gasoline rather than to sell as heating oil.

4. PRICE POLICY

4.1 PRICE POLICIES AND OBJECTIVES

From the modern firm's-eye view, competitive action can generally take three forms: (1) product improvements and new products, (2) sales promotion—advertising, introductory offers, etc., and (3) adjustments of selling prices.

A policy approach, which is becoming normal for other sales activities, is comparatively rare in pricing. Most well-managed manufacturing enterprises have a clear-cut advertising policy, product policy, customer policy, and distribution-channel policy. But pricing decisions remain a patchwork of *ad hoc* decisions, and are dealt with on a crisis basis. Price management by catastrophe discourages the systematic analysis needed for clear-cut pricing policies.

4.1.1 Kinds of competitive situations. Since different competitive situations require quite different pricing, good solutions for pricing problems require an understanding of the competitive environment in which the company sells its various products.

In pure competition, sellers have no pricing problems because they have no price discretion; they sell at the market price or not at all. Price policy has practical significance only when there is a considerable degree of imperfection in competition, enabling the firm to make some sales in spite of disparities with competitors' prices.

In our analysis of pricing, we shall be concerned with only those kinds of competitive structures that are thus marked by a zone of price discretion. On the basis of product, such competitive structures can be broken into three types, depending on whether the product has: (1) lasting distinctiveness, (2) perishable distinctiveness, or (3) little distinctiveness and a few competitive sellers. These three situations call for different kinds of price policy, which we shall discuss below.

Since product differentiation is of critical importance in price competition, it should be understood that the only kind of product distinctiveness or differentiation that is important in competitive relationships exists in individual buyers' minds, not in technical factual difference. Some people choose television sets on the basis of price alone, because all sets look alike to them; others choose on the basis of cabinet design alone, since they can understand appearance but not performance, and are willing to pay whatever price is asked; still others may choose on the basis of performance alone. Most of us, of course, care about several such product characteristics, or, if you please, product dimensions, and have to establish an optimum compromise position among them. Thus each seller can usually have a monopoly with a few buyers and, at the same time, be in strong competition for sales to others.

4.2 PRICING PRODUCTS OF LASTING DISTINCTIVENESS

A product with strong and durable distinctiveness—that is, a rock-ribbed monopoly—is so rare in our economy that we shall not take the space to discuss its appropriate price policy, which is well established in economics as the theory of monopoly pricing. The traditional keystones of monopoly—control of scarce raw materials, patents, economies of large-scale production—have become steadily weaker in the face of the recent advances of industry in substituting one material for another, one design for another, and one process for another to achieve a given objective. Many industries have found that inadequacies of patent protection make it more profitable to pool technical advances among firms than to try to exploit individual discoveries. It is often best to assume, therefore, that new products that are distinctive at the outset will inevitably degenerate over the years into common commodities, with the entry of competition.

4.3 PRICING PRODUCTS OF PERISHABLE DISTINCTIVENESS

The real monopoly pricing problem starts when a company finds a product that is a radical departure from existing ways of performing a service and that is temporarily protected from competition by patents, secrets of production, control of a scarce resource, or by other barriers. Since price policy will inevitably have a serious influence on the rate of degeneration in the product's distinctiveness, price policy must integrate a forecast of that decline with company objectives as to its ultimate market position for the product.

Forecasting the progress of the new product is actually forecasting three approximately parallel time paths: (1) technical maturity, indicated by declining rate of product development, increasing standardization among brands, and increasing stability of manufacturing processes and knowledge about them; (2) market maturity, indicated by consumer acceptance of the basic service-idea, by widespread belief that the products of most manufacturers will perform satisfactorily, and by enough familiarity and sophistication to permit consumers to compare brands competently; and (3) competitive maturity, indicated by increasing stability of market shares and price structures.

Of course, interaction among these components tends to make them move together—that is, intrusion by new competitors helps to develop the market. But entrance is most tempting when the new product appears to be establishing market acceptance.

What are the factors that set the pace of degeneration? An overriding determinant is technical—the amount of capital investment needed to use the innovation effectively. But aside from technical factors, the rate of degeneration is controlled by economic forces that can be subsumed under (1) rate of market acceptance, and (2) ease of entry.

"Market acceptance" means the extent to which buyers consider the product a serious alternative to other ways of performing the same service. The speed of market acceptance varies widely, from the slow growth of garbage-disposal units to the spectacular acceptance of antihistamine cold tablets, ball-point pens, and soil conditioners. Low unit cost (25¢ rather than $300) probably favors growth, and a past record of successful product innovations aids in giving consumers faith in the company's technical ability and honesty.

Ease of entry is even more difficult to analyze than market acceptance, but probably the most important factor to consider is competitors' capital resources for research and promotion. And of course the bigger the opportunity in a new product, the more capital there is available to invade your field.

4.3.1 Policies for pioneer pricing. The strategic decision in pricing a new product is the choice between: (1) a policy of high initial prices that skim the cream of demand; and (2) a policy of low

prices from the outset serving as an active agent for market penetration. Although the actual range of choice is much wider than this, a sharp dichotomy clarifies the issues for consideration.

Skimming price. For products that represent a drastic departure from accepted ways of performing a service, a policy of relatively high prices coupled with heavy promotional expenditures in the early stages of market development (and lower prices at later stages) has proved successful for many products. There are several reasons for the success of this policy:

(1) Demand is likely to be more inelastic with respect to price in the early stages than it is when the product is full-grown, particularly for consumers' goods. The public is still ignorant about the uses and limitations of the product, and there are frequently no readily apparent substitutes. Hence the people who are willing to buy tend to be adventuresome types who want to try out new ways of raising their living standards, and who are more susceptible to promotional effort than to price advantages.

(2) Launching a new product with a high price is an efficient device for breaking up the market. This is actually a form of price discrimination. After selling to the market described in (1) above, the price is slowly lowered to reach successively less daring customers until market saturation is sufficient to rob the product of all novelty.

(3) The skimming-price policy is safer, or at least appears so. That is, the company will not market the product at all unless initial prices cover the early high costs of production and selling—costs that, if success were certain, would be considered part of the investment outlay in the new product.

(4) Many companies are not in a position to finance the product flotation out of distant future revenues, even when the effects on market expansion make a low initial price clearly more profitable than a high price. High initial prices thus finance the costs of raising a product family when uncertainties block the usual sources of capital.

Penetration price. The alternative policy is to use low prices as the principal instrument for penetrating mass markets early. This policy is the reverse of the skimming-price policy, in which price is lowered only as short-run competition forces it. The orthodox skimming policy has the virtue of safeguarding some profits at every stage of market penetration. But it prevents quick sales to the many buyers at the lower end of the income (or preference) scale who are unwilling to pay any substantial premium for novelty or reputation superiority. The active approach in probing possibilities for market expansion by early penetration pricing requires research, forecasting, and courage. The low-price pattern should be adopted with a view to long-run rather than to short-run profits, with the recognition that it usually takes time to attain the volume potentialities of the market.

What conditions warrant aggressive pricing for market penetration? First, there should be a high responsiveness of sales to reductions in price. Second, savings in production costs as the result of greater volume should be substantial. Third, the product must be of such a nature that it will not seem bizarre when it is first fitted into the consumers' expenditure pattern. Fluorescent lighting, which exemplifies these three traits, showed a dramatic growth of sales in response to early penetration pricing.

A fourth condition that is highly persuasive for penetration pricing is the threat of potential competition. One of the major objectives of most low-pricing policies in the pioneering stages of market development is to raise entry barriers to prospective competitors. But stay-out pricing is not always appropriate; its success depends on the costs of entry for competitors and on the expected size of market. When total demand is expected to be small, the most efficient size of plant may be big enough to supply over half the market. In this case, a low-price policy can capture the bulk of the market and successfully hold back low-cost competition, whereas high prices are an invitation for later comers

to invade established markets by selling at discounts. In many industries, however, the important potential competitors are large multiple-product firms for whom the product in question is probably marginal. For such firms, present margins over costs are not the dominant consideration, because they are normally confident that they can get their costs down as low as competitors' costs if the volume of production is large. Thus, when the total market is expected to stay small, potential competitors may not consider the product worth trying, and a high-margin policy can be followed with impunity.

On the other hand, when potential sales appear to be great, there is much to be said for setting prices at their expected long-run level. A big market promises no monopoly in cost savings, and the prime objective of the first entrant is to entrench himself in a market share. Brand preference costs less at the outset than after the competitive promotional clamor has reached full pitch. An off-setting consideration is that, if the new product calls for capital recovery over a long period, there is a risk that later entrants will be able to exploit new production techniques which undercut the pioneer's original cost structure.

Profit calculation should recognize all the contributions that market-development pricing can make to the sale of other products and to the long-run future of the company. Often a decision to use development pricing will turn on these considerations of long-term impacts on the firm's total operation strategy rather than on the profits directly attributable to the individual product.

An example of market-expansion pricing is found in the experience of a producer of asbestos shingles. Asbestos shingles have a limited sale in the high-price house market. The company wanted to broaden the market in order to compete effectively with other roofing products for the inexpensive home. It tried to find the price of asphalt shingles that would make the annual cost per unit of roof over a period of years as low as the cheaper roofing that currently commanded the mass market. Indications were that the price would have to be at least this low before volume sales would come. Next, the company explored the relation between production costs and volume, far beyond the range of its own volume experience. Variable costs and overhead costs were estimated separately and the possibilities of a different organization of production were explored. Calculating in terms of anticipated dollars of profit rather than in terms of percentage margin, the company reduced the price of asbestos shingles and brought the annual cost down close to the cost of the cheapest asphalt roof. This reduction produced a greatly expanded volume and secured a substantial share of the mass market.

4.4 PRICING STANDARD PRODUCTS WHEN COMPETITORS ARE FEW

In this section we discuss oligopoly, the third competitive situation where price policy is an important management problem. Oligopoly is competition where three, four, or fifteen firms have not only similar products but roughly similar production costs. Usually, rivals' products are sufficiently different in buyers' minds to make brands an important feature in marketing and to allow differences in prices, yet sufficiently similar to make a seller watch rivals' prices closely.

In industries where a few competitors dominate the supply of relatively uniform products, periods of low demand and excess capacity create serious competitive problems. This is particularly so in industries with heavy plant investments, and high barriers to entry. Each manufacturer is aware of the disastrous effects that an announced reduction of his own price would have on the prices charged by competitors. As a result, these companies have by experience developed a pronounced aversion for attempting to gain market share by open price cutting. Under these circumstances, market share

is largely determined by secret price concessions and by non-price competition.

When the dynamic changes in demand and cost conditions that prompt a given price change are viewed in much the same way by all rivals, they do not cause serious uncertainties concerning rivals' reactions. But these uncertainties do become serious: (a) when rivals are quite differently affected by the same general changes in conditions, (b) when rivals differ in their estimates concerning the future conditions for which they are pricing, and (c) when rivals have drastically different notions about the effectiveness of price changes.

Since these disruptive influences are continually at work to some degree in many industries, a critical problem of oligopoly is to devise industry practices that can reconcile the need for adjustments to changing industry demand with the need to maintain the precarious price structure that has been established.

Two important releases from this dilemma are (1) non-price competition and (2) price leadership. When these are inadequate or slow to relax conflicting pressures in a new demand situation, there are still several varieties of underground price competition that can be used to maintain a facade of industrial peace in the industry without resorting to war. We shall discuss these here.

4.4.1 Non-price competition. Non-price competition is viewed with far more equanimity than price-cutting, and is frequently quite unrestrained. The basic reason may be that retaliation is much more difficult against advertising or product improvements than against price-cutting. The great variation in efficiency of marketing activities demonstrates the importance of "know-how" barriers to retaliation. The best way of doing things is too peculiar to each firm's situation to permit speedy imitation. Retaliation therefore often takes a different route. A sampling campaign by one soap manufacturer is met by a contest rather than by a duplication of the sampling campaign Furthermore, the sales effects of a particular promotional stratagem are far less clear than the effects of price-cutting, and there is usually a less compelling necessity to retaliate.

4.4.2 Price leadership. The institution of price leadership is another way for oligopoly competitors to achieve the delicate adjustment to changing cost and demand conditions without precipitating a price war. One firm takes the initiating role in all price changes, and the other firms follow along, matching the leader's price exactly, or with established differentials. Price leadership in action may be seen most clearly in a mature and stable industry with a standardized product, such as steel, oil, cement, or building materials. But it plays an important part in many industries that have considerable product differentiations.

Price leadership greatly reduces the number of possible reactions of a price change, and thus gives a modicum of certainty to the pricing aspects of market forecasting. All that is needed is one firm whose price policy is consistently acceptable to most of the industry. The form that leadership actually takes depends on the size structure of the industry's firms, on disparities in their cost functions, product differentiation, and geographical distribution, and on the pattern and stability of demand. In the more sophisticated industries, there is a feeling of mutual responsibility of the leader to set prices that other firms can live with, and of the followers to follow the leader in the best interests of the group.

Problems of the price leader. Broadly conceived, the problem of the price leader is a problem of industrial statesmanship, particularly when industry conditions are changing rapidly. If he fails to reconcile his own and the industry's interests with those of the followers, he may easily impair his own position in leadership and market share.

In many industries, price leadership has been fairly responsive to changes in cost and in demand, and at the same time has managed to dampen the amplitude of cyclical fluctuations. Under leadership, prices have not gone as high in boom periods or as low in depressions. Price leadership usually produces few,

but large and dramatic, price changes in the industry over the cycle. After World War II, a few leaders, notably International Harvester and General Electric, tried lowering prices in an attempt to curb inflation, but they were too far out of line with market conditions to be followed. They subsequently raised their prices again.

Even in normal conditions, however, the leader usually leads only in price rises. Any competitor can lead real prices down, and usually nominal followers take the initiative here.

It is important for the leader to know how long the lower price level will last. A temporary drop should be met only by informal concessions from the official price, since frequent changes in announced prices disrupt the followers' adjustments and weaken the leader's prestige. Only when market weakness indicates a fairly long-run shift in conditions should the major move of changing official prices be made. The price leader often merely formalizes what is generally recognized as inevitable in the trade, or merely forecasts sooner, and more accurately, what later becomes recognized. Forecasting is thus a critical part of leadership. It determines what attitude to take toward a deteriorating market and it signals the time for an advance. If forecasts of developing cost and demand conditions are accurate and trusted by the industry, there are substantial gains, but when the leader has a history of blunders, followership is weak and the leader can only formalize changes that are generally recognized as inevitable in the trade.

4.4.3 Underground price competition. The discussion of price leadership has indicated that the most important device for short-run sales expansion is the secret price concession. The form of the concession is not important, so long as the buyer understands the real offer. It may take the form of high turn-in values, down-grading of high-quality lines, better payment terms, and so forth. Underground price competition in the tire industry takes such forms as concessions to mail-order houses and filling-station chains, and special prices for "test tires" (allegedly slightly used).

The industry leader has the problem of determining whether and how to reduce the level of official prices to meet undercover concessions. When are undercover concessions significant enough to warrant open reduction of prices? Here are a few strategic indicators:

1. When they spread over a wide geographic area.
2. When they continue for several months.
3. When first-line competitors indulge quite generally in undercover cutting.
4. When the price-cutter is out to broaden the market. If his motive seems to be to capture a bigger market share by secret concessions, the leader may merely meet these informal concessions.

The main economic function of underground price competition is to give resilience and stability to an otherwise brittle oligopoly situation. Undercover price concessions make it possible to develop an informal hierarchy of prices which allows products of sub-standard acceptance a share of the market without setting off a price war.

4.5 COST-PLUS PRICING

Surveys of actual business practice in setting prices have indicated that the most pervasive pricing method used is to make a cost estimate and to add a margin of some kind for profit—what is known as cost-plus pricing. Cost-plus pricing is so extensively used and at the same time so difficult to reconcile with economic theory that it deserves special attention.

4.5.1 Determination of profit mark-up. The percentage that is added for profit in cost-plus formulas differs strikingly among industries, among member firms, and even among products of the same firm, although it has been suggested that 10 per cent is a typical figure. Some of this variation may be due to differences in competitive intensity, some to differences in cost base (e.g., the degree to which profit has already been included

by padding of overhead), and some to differences in turnover rate and risk. The size of this profit factor, however, often reflects habits or custom and some vague notion of a "just" profit.

The size of the mark-up can be determined rationally only in terms of sales forecasts, cost forecasts, and some criterion of an acceptable or goal rate of return. But any rate-of-return standard is essentially arbitrary—i.e., there are no economic guides to rate-standards except "all you can get"—and cost-plus pricing is fundamentally a denial of this economic doctrine. Within the cost-plus framework, perhaps the most sensible standard is a recent average return of companies that are comparable in products, processes, and risks. Such a standard provides some measure of the competitive return that is allowable in the industry without loss of market shares or invasion of markets.

4.5.2 Inadequacies of cost-plus pricing. The popularity of the cost-plus method does not mean that it is the best available method. In most situations it is not, for several reasons:

1. It ignores demand. What people will pay for a product bears no necessary relation to what it costs any particular manufacturer to make it.

2. It fails to reflect competition adequately, especially the effect upon the birth of potential competition.

3. It overplays the precision of allocated costs—that is, costs that are common to several products and must be distributed among the products by some arbitrary rule.

4. It is based upon a concept of cost that is frequently not relevant for the pricing decision. For many decisions, incremental costs rather than full costs should be controlling, and opportunity costs—i.e., alternative uses of facilities —are not reflected in accounting systems.

5. It involves circular reasoning in some degree if current full cost is used as the base. To the extent that unit costs vary with output, and thus with sales volume, this cost depends partly on the price charged, provided that demand has significant elasticity and fixed overhead is important.

4.5.3 Justification of cost-plus pricing. In defense of cost-plus pricing, the following arguments have been marshaled for particular situations:

1. It is a resort of desperation, in the absence of the knowledge required for more reasonable methods. It is difficult to estimate at all precisely the impact of price upon sales volume. Ignorance of the firm's demand curve obviously makes it impossible to take its influence on price into account. The reaction of rivals to a given price policy that has a pronounced effect upon volume is also hard to forecast. The effect of today's price on tomorrow's demand and upon potential competition may also be hard to estimate. Faced with the necessity of guessing at almost every factor that ought to enter into scientific pricing, executives often take refuge in the pseudo-certainty of a price built up by rather arbitrary mark-ons from a cost bench that is "known" but not always relevant.

2. It is the safest though not the most profitable method of pricing. In pricing a new, made-to-order article, a cost-plus formula may set what amounts to a refusal price. The seller automatically saves himself from tying up facilities with work that would yield subnormal profits.

A major uncertainty in setting a price is the unknown reaction of rivals to that price. When the products and production processes of rivals are highly similar, cost-plus pricing may offer a source of competitive stability by setting a price that is more likely to yield acceptable profits to most other members of the industry.

Another kind of cost-plus safety pricing is based on some sort of Jeremiah criterion. By envisioning the worst probable cyclical demand shift, a price is built up that will produce a predetermined profit level under these circumstances. An example is pricing to break even at 30 per cent capacity. Pricing to cover bond interest at x per cent capacity is another version.

3. Most new products are molded to meet a zone of competitive price, and much selling effort goes into giving the maximum quality in that price range. In an extreme form, a selling price is predetermined exactly, and by working back from this, product cost, and hence design, are arrived at.

4. Another situation in which cost is an unusual limiter of price is in selling to a few powerful and knowledgeable buyers. An example is the automobile parts industry, where buyers know a great deal about suppliers' costs and are in a position to make the product themselves if they don't like the seller's prices.

4.6 PRICE DIFFERENTIALS

There are at least two parts to a complete price policy. The first is the method for determining the basic list price of a product, which has been the subject of this article so far. The second part, the subject of the rest of the article, is the system for determining the net price actually charged particular customers, that is, the system for price variation related to *conditions of sale:* (1) the trade status of the buyer, (2) the amount of his purchase, (3) the location of the purchaser, (4) the promptness of payment.

The average net realized price per unit obtained by the manufacturer depends not only upon the formal structure of price differentials for various classes of purchases, but also upon the proportion of sales made in each class, and the departures from formal price structures. Consequently, competitors usually differ in net realization per unit, even when their formal price structures are quite similar. For these reasons, and because of differences in formal discount structures, there is often little relation between the average recovery to the manufacturer per unit and the list prices of competitive products.

4.6.1 Goals of differential prices. From the seller's standpoint, the differential prices that result from the application of various discount structures and from product-line pricing may serve several purposes. It is, therefore, desirable to look first at the company's whole structure of price differentials in terms of these purposes, which may be grouped as follows:

1. **Implementation of marketing strategy.** The patterns of price differentials (product-price differentials and the various discount structures) should implement the company's over-all marketing strategy. These price differentials should be efficiently geared with other elements in the marketing program (e.g., advertising and distribution channels) to reach the sectors of the market selected by strategy. In doing so, the job of a particular structure of discounts may be quite specific. For example, an oil company whose strategy was directed at large and few service stations served by giant transport trucks would grant large quantity discounts for big purchases.

2. **Market segmentation.** A major objective of differential prices is to achieve profitable market segmentation when legal and competitive considerations permit discrimination.

The practical problem of putting price discrimination to work involves breaking the market into sectors that differ in price elasticity of demand. To the extent that it is feasible to seal off such segments of the market, charging different prices for different sectors can increase the total volume of sales. Price discounts of various sorts are a major means of achieving market segmentation.

3. **Market expansion.** Differential pricing that is designed to encourage new uses or to woo new customers is a common goal of product-line pricing, but it also extends over various phases of the discount structure, depending upon the circumstances of a purchase by a new user.

4. **Competitive adaptation.** Differential prices are a major device for selective adjustment to the competitive environment. Discounts are often designed to match what competitors charge under comparable conditions of purchase, in terms of net price to each customer class. When products are homogeneous, com-

petitive parity is a compelling consideration.

5. **Reduction of production costs.** Differential prices can sometimes help solve problems of production. Seasonal or other forms of time-period discounts may be partly for the purpose of regularizing output by changing the timing of sales. For example, since electricity cannot be stored, classifications of electric rates are designed to encourage off-season uses and to penalize uses that contribute to peaks.

The discount structure is the main area for adaptation of prices to changed economic conditions and competitive status. A drop in demand hits the discount structure first, and its first impact there results in secret shading of quantities and classifications. Similarly, a competitor who is at a disadvantage in the quality, reputation, or distribution of his products uses the informal or formal structure of discounts to even up these weaknesses.

4.6.2 Distributor discounts. Distributor (or trade-channel) discounts are deductions from list price that systematically make the net price vary according to the buyers' position in the chain of distribution. These differential prices distinguish among customers on the basis of their marketing functions (e.g., wholesaler vs. retailer), and are thus also called "functional discounts." Special prices given to manufacturers who incorporate the product in their own original equipment (e.g., tires and spark plugs sold to automobile manufacturers), special prices to other members of the same industry (e.g., gasoline "exchanges" among petroleum companies), and special prices to the Federal Government, to state governments, and to universities, are examples of common forms of discounts that are close enough to trade-channel discounts to be grouped with them. Table 2.3 shows several typical trade-discount structures.

The economic function of distributor discounts is to induce independent distributors to perform marketing services. To build a discount structure on a sound economic basis, it is necessary to know: (1) the objectives of the discount structure, (2) distributors' operating costs, (3) discount structures of competitors, (4) opportunities for market segmentation.

Objectives. To find out exactly what services the manufacturer wants from each type of distributor requires a broad, carefully thought-out distribution plan that fits the product, the competitive position of the seller, and the folkways of the industry. The primary consideration in working out such a plan is the allocation of marketing functions between the manufacturer and the distributing chain and among the links in that chain. The problem is to find which functionary can do each specific job most economically and effectively. For example, a large electrical manufacturer selling refrigerators through distributors and dealers decided that in one of its major markets the function of the retail dealer should be confined to displaying six basic models, taking orders for them, and arranging the terms of the individual transactions. In the plan that this manufacturer worked out, the wholesaler, in addition to his traditional function of selecting the dealers and helping them do a better selling job, receives the merchandise, inspects it, delivers it to the customer's premises, installs it, and takes complete charge of all subsequent mechanical service.

Distributors' operating costs. The most important function of trade-channel discounts is to cover the operating costs and normal profits of distributors. Discounts should be closely aligned to these costs if distributors are to play the part planned for them. Margins that are too rich produce excess selling effort or too many distributors, while margins that don't cover costs will not move the goods.

Should trade discounts be determined by the costs of the inefficient distributor or by the costs of the efficient distributor? One solution to this problem is to set trade discounts to cover the estimated operating costs (plus normal profits) of the most efficient two-thirds of the dealers. When cost estimates are uncertain, a practical test of excessive

TABLE 2.3 TRADE-CHANNEL DISCOUNTS IN VARIOUS INDUSTRIES*

Channel Discounts
(from list price)

Type of business	Manufacturer's agent	Distributors	Wholesalers	Dealers
Air Conditioning	50 & 10%		50%	40%
Automotive Accessories	50 & 10%		50%	40%
Electrical Appliances		40 & 20%		35 or 40%
Farm Equipment			25%	30%
Heating Controls	40 & 10 & 10% indiv. units; 50 & 10% package units		40 & 10% indiv. units; 50% package units	25 & 5% indiv. units; 33⅓% package units
Machinery	5%			30% stocking 10% non-stocking
Motorcycles		30% motorcycles; 50% parts		25% motorcycles 45% parts
Musical Instruments—Percussive			50 & 10%	50%
Office Supplies	10% commission		50 & 20%	50%
Radios	2 & 10% commission		60%, 60 & 5%, 60 & 10%, 50 & 10% (varies with line & quality)	40%; on certain line 33⅓%
Scales	50 & 10%		50%	40%
Industrial Division	50%			
Stoves and Heaters			33⅓ & 25% or 40 & 25% if bought in carload lots	33⅓% deluxe models 40%
Toys	5%		50 & 5%	40%
Water Coolers			40 & 5% max.	30 & 5% max.

* Trade Discount Practices, Report No. 558, The Dartnell Corp., Chicago. Reproduced in Dean, *Managerial Economics*, p. 520.

margins is the extent to which rehandlers expass margins on by knocking down realized prices.

Another check on distributors' costs is an estimate of the manufacturer's cost of performing the distributive function himself. Many companies periodically consider doing more of the marketing job themselves (e.g., bypassing the wholesaler), and such estimates are frequently available as by-products of these trade-channel policy studies. Moreover, some companies operate through different channels in different sections of the country, and thus have some cost experience in performing distributive functions.

Competitors' discount structures. In a sense, dealer discounts are a means of purchasing the dealer's sales assistance in a competitive market. In many industries the actual (as opposed to the nominal) discounts granted by rival sellers vary. The manufacturer must decide whether he is to be guided by the higher or by the lower discounts. Specifically, a manufacturer whose product is at some disadvantage in consumer ac-

ceptance may consider making an attempt to buy distribution by granting larger margins than do competitors. The success of such an effort usually depends on whether the margin incentive will actually induce the distributor to push the product; and whether competitors are likely to meet the wider margins.

The competition from substitute distribution channels should also be studied. Costs of alternative routes may place the selected channel at a disadvantage in terms of the ultimate price to the consumer for a comparable product-service combination. This factor may set ceilings on channel discounts for a chosen distribution route. Cheap substitute channels have been a salutory stimulant for the seller to seek more effective channels.

Opportunities for market segmentation. Trade-channel discounts can be one means of achieving profitable market segmentation.

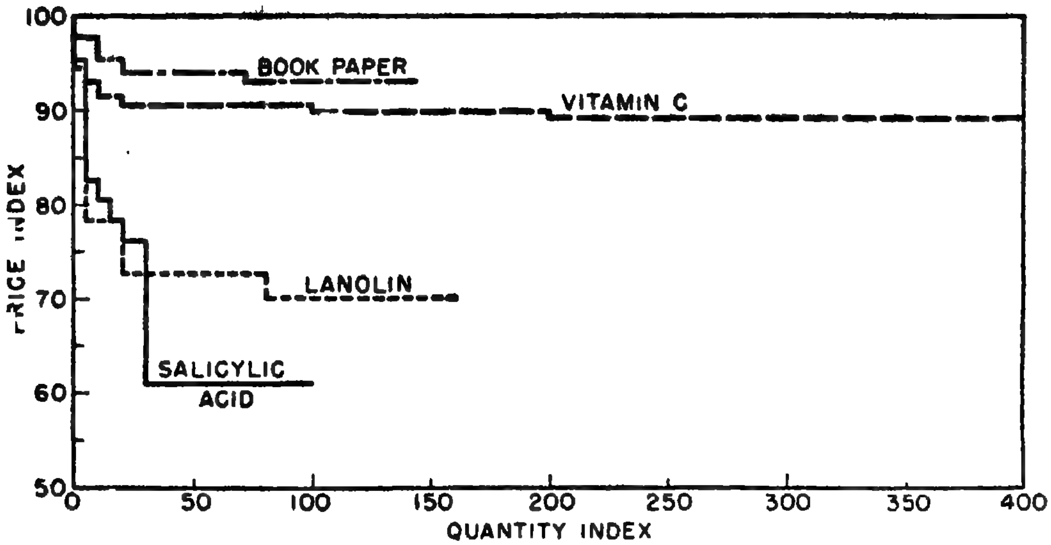
In some industries, the market is broken down into several fairly distinct sub-markets, each of which has its own peculiar competitive and demand characteristics. These sub-markets provide a ready-made opportunity for market segmentation. In the tire market, for example, the following sub-markets may be distinguished:

1. The original-equipment market, characterized by skill and bargaining strength of buyers and by big cyclical fluctuations in demand.
2. The individual-consumer replacement market, characterized by unskilled buying, brand preferences, and cyclical stability.
    a. The manufacturer's brand segment.
    b. The distributors' brand segment.
3. The commercial-operator replacement market, characterized by large buyers who are price-wise and quality-wise (e.g., bus companies).
4. The government-sales market, characterized by large orders, formal bids, and publication of successful bidder's price.
5. The export market, characterized by international competition.

Price discrimination among individual consumers in the retail market is a common form of market segmentation. The manufacturer's pricing problem here is whether to keep the initial margins high enough to permit dealers to make individual concessions to customers. Realized margins that are substantially lower than official margins do not necessarily mean that the official margins should be reduced. This disparity may be justified in industries where competition at the dealer level is strong and where opportunities for personal differentiation are important. A dealer can then get the full price from some customers who are averse to shopping and bargaining and can give substantially lower prices, with the flavor of a bargain, to more careful shoppers. This kind of individual pricing can yield a higher dealer profit than can uniform pricing. A conspicuous example of such pricing is found in the operation of automobile dealers under normal competitive conditions. It is normally appropriate to permit the dealer considerable latitude when the unit cost of the article is high, when trade-ins and service concessions provide a convenient mechanism for veiled price reductions, and when the customer is not tied tightly to the dealer by strings of continuity of service or by customer relations.

4.6.3 Quantity discounts. Quantity discounts are reductions in the net price that are systematically related to the amount purchased. Our analysis is confined to commercial discounts. It does not include package-size differentials at the consumer level. Illustrations of commercial quantity-discount structures are found in Fig. 2.7.

The essential problem for management in quantity discounts is to decide how big they shall be. What merchandising job do we want quantity discounts to do? One important job of quantity discounts is to reduce both the number of and the losses from small orders. It is common for a firm to find that 80 per cent of its orders account for only 20 per cent of its sales, and the cost of making these sales frequently causes an actual out-of-pocket drain of cash. Quantity discounts can help correct the size-distribution of



Dean, *Managerial Economics*, p. 530.

FIG. 2.7 QUANTITY DISCOUNT STRUCTURES.

orders in three ways: (1) They may stimulate a given set of customers to order the same amount of business in bigger lots. (2) They may induce the same customers to give the seller a larger share of their total business in order to get savings of quantity buying. (3) They may turn away small accounts and attract bigger accounts, thus altering the size-distribution of the customers themselves.

To manipulate the size distribution of orders, the discount system must be framed in reference to competition. The seller must decide, by over-all market strategy, which competitors he wants to better in what sectors of the market. The important factor competitively is the actual net prices charged to strategic customer classes, not the formal quantity-price structure *per se*. In some situations there is no room for such pin-pointing of market targets, since discount structures of the industry are uniform, and deviations will be met by retaliation in some form. But frequently there are differences in the net quantity prices offered by various competitors to a given category of trade. The quantity-discount structure can then be integrated with the company's selling strategy and assigned a designated part of the total distribution job.

Legality. Quantity discounts have been a question of much litigation by the Federal Trade Commission, and any structure being considered must be scrutinized closely for its legality. While this is a technical subject much beyond the scope of a handbook, it can be noted that legality hinges largely on proved cost savings resulting from large orders, and that, by and large, cost savings are provable only in the selling and distribution expenses of filling the order.

4.6.4 Cash discounts. Cash discounts are reductions in the price which depend upon promptness of payment. Probably the most typical cash discount terms are 2 per cent off if paid in 10 days, full invoice price due in 30 days. The cash discount is a convenient way to identify bad credit risks. In some of the garment trades, where mortality is notoriously high, the cash discount is as high as 8 per cent, which makes the full wait extremely expensive competitively. The higher price to the credit buyer thus reflects his weak bargaining position.

Unfortunately, there is no real information on the effects of cash discounts on bad-debt losses and on speed of collection. Immediately following World War II, many companies drastically reduced or eliminated cash discounts.

4.6.5 Geographical price differentials. Geographical discount structures are important when transportation costs are high relative to selling price. They take a variety of forms, and the best one to

use depends on the location of markets and competitors, and on industry practice. All systems except F.O.B. mill pricing are under a legal cloud, since they are practical means for covert collusion. But some form of delivered prices may be essential for reaching a nationwide market under some industry conditions.

5. CAPITAL BUDGETING

This article is concerned with the economics of capital budgeting—that is, with the kind of thinking that is necessary to design and carry through a systematic program for investing stockholders' money. Planning and control of capital expenditures are the basic executive functions, since management is originally hired to take control of stockholders' funds and to maximize their earning power. (See also Section 16.)

Although capital budgeting is conceptually at least the universal business problem that encompasses all others, few executives are happy with their own solutions to it. Capital-budget reviews take too much time, and without systematic rejection and acceptance criteria the pivotol decision on the size of the total expenditure that should be authorized in a given year has no solid foundation. Allocation of funds among projects, moreover, is often determined by skill and persistence of persuasion rather than by objective indexes of company welfare.

5.1 MEANING OF CAPITAL EXPENDITURE

A capital expenditure should be defined in terms of economic behavior, rather than in terms of accounting conventions or tax law. The criterion, then, is the flexibility of the commitment involved—that is, the rate of turnover into cash. For instance, inventories and receivables, although assets on the balance sheet, turn over fast enough to make their level fairly adjustable to short-run changes in outlook. They are, therefore, excluded from the capital budget. Major replacements or additions to plant capacity, on the other hand, take several years to return their cash outlay. Their value to the company during this period is usually much above the amount they could be sold for—that is, they tie up capital inflexibly for long periods. They involve more uncertainty, forecasting judgment, and company-wide thinking than an inventory investment does, and justify a special procedure for management review. The same is largely true for major research on new products and methods, and for advertising that has cumulative effects. It applies as well to costs of educating executives and developing dependable distribution connections.

This definition of outlays that are budgeted as capital expenditures does not correspond well to the accounting distinction between capitalized and expensed outlays. Although it includes most items capitalized by accountants, it also includes some important expenditures that are usually expensed by accountants, such as long-term advertising, training, and research. The disparity hinges largely on the tangibility of an asset rather than on its economic nature, and contrasts the need for controls and conventions in accounting with the economist's need for relevant and inclusive concepts.

5.2 NATURE OF BUDGETING PROBLEM

The capital-budgeting problem consists broadly of three questions: (1) How much money will be needed for expenditures in the coming period? (2) How much money will be available? (3) How should the available money be doled out to candidate projects? The first question is that of demand for capital, and since the objective of capital expenditures is to make profits, "need" should be measured by prospective profitability. Thus this problem involves a survey of opportunities for profitable internal investment and implies some system of screening requests on the basis of prospective profitability.

The second question concerns capital supply. This problem has two parts: (a) How much can be raised internally from depreciation plus retained earnings? (b) How much will be obtained by outside financing?

The third question, how to ration funds, is the crux of the budgeting problem, the point where it becomes evident how much should be spent in total and where.

5.3 DEMAND FOR CAPITAL

The usual starting point of a capital-expenditure budget is a survey of the company's anticipated needs for capital. This inventory of internal investment opportunities is usually built up from the smallest operating units of the organization, often as an integral part of annual budgets or general development plans for a longer period. The catalogue of capital "needs," expressed in terms of specific individual assets, moves up the management hierarchy for supervisory review and for aggregation into larger managerial units.

The discovery and development of good investment proposals usually require effort. Hence encouragement of an imaginative search for such opportunities is an important part of the program. The activities of the research department and the industrial engineering group in reducing costs and improving products generally produce opportunities for profitable investment. Good projects also result from research and competition in the equipment industries whose business it is to promote their own sales by creating obsolescence.

Surveys of explicit capital requirements are generally confined to one year, or at most two years, ahead. The capital projects themselves are hard to visualize in the distant future, since they depend upon unborn technical advances and long-range development of demand for the company's product. And even when projects are foreseeable, their prospective earnings are highly uncertain, for they too depend upon unknown technical advances, market developments, and changes in relative prices.

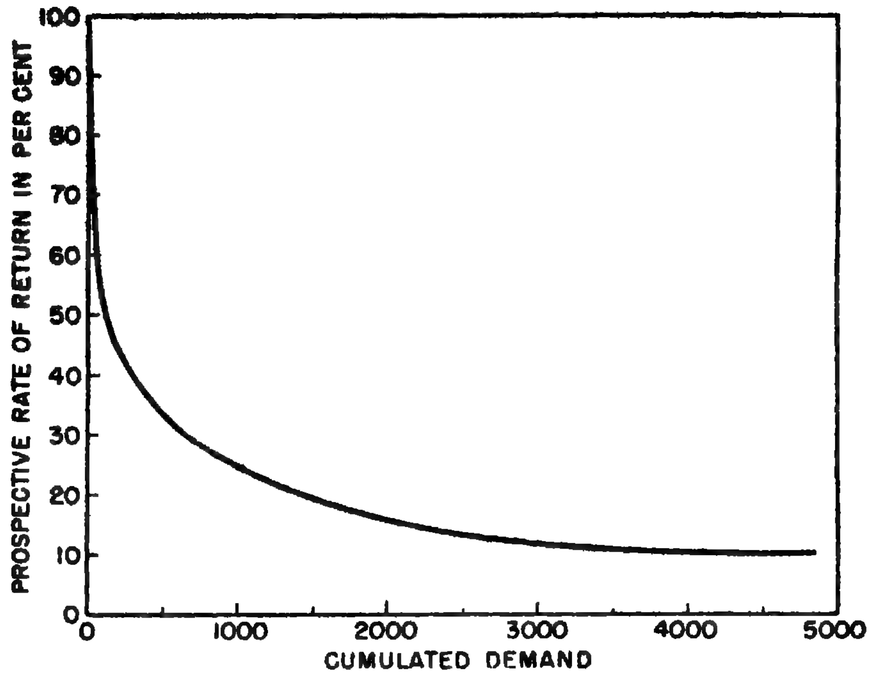
5.3.1 Nature of demand for capital. Surveys of capital requirements are often phrased in terms of "need." How much new capital will a given plant or marketing district "need" to do a good job during the planning period? But "need" is a meaningless concept for economic analysis, since it contains no objective measurement of intensity. "Demand" for capital, in contrast, measures the intensity of need for capital by its earnings. Under most circumstances, the underlying source of demand for capital expenditures is, or should be, prospective profitability.

To develop an empirical approximation to the company's demand schedule for capital for internal investment during a specified time period, it is necessary: (1) to marshal all individual "needs" for capital expenditures that can be discovered and foreseen throughout the company; (2) to estimate for each proposal its prospective productivity in the form of rate of return on the added investment; (3) to array projects in a ladder of rate of return (as illustrated by Table 2.4); and (4) to cumulate this ladder in the form of a schedule showing the amount of money that can be in-

TABLE 2.4 DEMAND SCHEDULE FOR CAPITAL*

(a) *Prospective rate of return*	(b) *Volume of proposed investments*	(c) *Cumulative demand*
Over 100%	2	2
50-100%	38	40
25- 50%	200	240
15- 25%	1200	1440
5- 15%	3400	4840

* From Dean, *Managerial Economics*, p. 560.



Dean, *Managerial Economics*, p. 561.

FIG. **2.8** DEMAND FOR CAPITAL.

vested to equal or better each of a series of rates of return. Figure 2.8 diagrams the resulting capital-demand schedule. In drawing such a schedule, the time span must be specified; for simplicity we shall assume the common one-year capital planning period. (See also Section 16.)

5.3.2 Principles of measuring capital earnings. The crucial estimate in analyzing demand for capital is the productivity (i.e., rate of return) of each proposed capital expenditure. Since capital productivity is the key factor in sound budgeting of internal investments, the care and precision with which it is estimated are likely to make the difference between good investment decisions and bad ones. Some important general principles for estimating capital productivity are summarized here.

1. Recognition of the source of productivity of capital is essential to correct estimation of capital earnings. The source of earnings depends upon the nature of the investment. The most important direct sources are cost savings and sales expansion. Cost savings are the source for investments in replacement and modernization of equipment. Added sales volume (or more profitable volume) is the source for investments that involve new products or expansion of capacity to produce old ones. Earnings of many projects have more than one source.

2. Earnings must be estimated on an individual project basis. It is the prospective profitability of *individual units of added* capital investment that is the key to their appraisal in allocating capital funds. Return on old, sunk investments has only historical interest and no relevance to decisions on new investments. And average return on old and new investments is badly misleading.

3. It is *future* profit on additional investment that is relevant. Thus, profit projections must be based on estimates of future prices, future costs, and so forth. The record of the past is useful only as a guide to estimates of the future.

4. Capital productivity estimates usually should involve comparison of future costs and profits with the *appropriate alternative*. An analysis of what will happen if no investment is made will reveal the proper alternative, i.e., the least-cost method without added capital.

5. Capital productivity should be measured by earnings over the whole life of the asset, even though in practice the

view of the distant future is often browned out. Estimates of economic life are always inexact, but they are essential for measuring capital wastage costs. Payout period—i.e., the number of years required for gross earnings (or cash savings) to pay back the capital investment —is a misleading measure of capital productivity. It is relevant solely for cash budgeting, and then only when confined to cash earnings (or savings).

6. Estimates of earnings (whether from cost savings or from added profits) should take account of the indirect effects of the proposed capital outlay upon the operation of existing facilities. Total company revenues and costs with the proposed investment should be compared with what they will be without it. Typically, estimates of these indirect earnings involve a high order of judgment and have wide error margins.

7. Estimates of the productivity of capital expenditures will differ in inherent riskiness and in the width of error margins. Some systematic method for allowing for these differences in risk and for comparing investment proposals is desirable.

8. For some kinds of investments it is impractical to estimate a rate of return. The benefits are so diffused and conjectural (e.g., research laboratories and employee club houses) that they defy quantification. Earnings of others are so high and so apparent (e.g., replacing a washed-out railroad bridge) that estimating a return is an academic exercise. Earnings on other projects are patently too low to warrant return estimates. Capital productivity should be measured only when there is a factual foundation for estimates and for projects of borderline productivity.

5.4 SUPPLY OF CAPITAL

Supply of capital is the problem of where the money will come from and how much will be available.

A useful distinction can be made between internal and external sources of capital funds. The chief internal sources are: (1) depreciation charges and (2) retained earnings. External sources are principally sale of securities to insurance companies and to the public. In the internal disposition of these funds no distinction should be made on the basis of sources of funds. In particular, the internal investment process should deal with gross rather than with net business savings—that is, with income before depreciation allowances. This gives a desirable fluidity of the internal investment process, where old, dying products can subsidize new ones by contributing funds that are not "earned" according to a "net" income concept. The barrier that depreciation charges set up against capital leakage from the firm may do more harm than good if it blocks flow of capital inside the firm. That is, the practice of allowing each of a company's divisions or plants to reinvest its own depreciation charges without central-office review carries division autonomy too far and undermines a major advantage of multiple-product firms. Cash earnings, rather than net earnings, should be pooled in a centrally administered supply of capital.

5.4.1 Internal sources. The principal managerial problems in connection with internal sources are (1) to forecast how much cash will be generated internally, (2) to decide how much cash to pay out in dividends, and (3) to decide how much of the remainder may be tied up in long-term projects.

In some companies, capital expenditures are confined completely to the amount that can be obtained internally. This may be a matter of choice or a matter of necessity because of the condition of the capital markets or the investment status of the firm.

Consequently, the projection of the amount that can be expected from accumulated depreciation and retained earnings is usually the most important part of capital-expenditure budgeting. Some companies make elaborate five-year forecasts of the cash that will be generated and of its disposition for dividends and for liquid reserves. More commonly, such estimates are confined to a one-year or two-year period. Such projections are

not only a matter of forecasting the level of sales prices and costs; they also involve management decisions on the adequacy of depreciation charges, the level of dividends, and the necessary degree of liquidity.

Plow-back guides. The importance of retained earnings as a source of capital funds makes plow-back policy an integral part of a firm's capital-expenditure budgeting. How should a company decide how much of its earnings to plow back and how much to pay out?

One guide to plow-back policy is that outlined by the capital rationing theory set forth below. If a company follows this plan faithfully, it retains earnings (up to the limit of stockholder rebellion) so long as they can be invested at a return higher than the firm's cost of capital (e.g., 15 per cent). It pays out earnings that cannot be invested internally at rates higher than this cost-of-capital rate.

Another guide is suggested by the theory that dividends in the modern corporation are really interest income. If plow-back policy is determined by this theory, then retained earnings is a highly volatile residual left after paying stable dividends out of fluctuating earnings.

A third rule for plow-back policy is that a certain percentage of earnings should be held back for contingencies and for growth. This is a long-run view of an average minimum amount of plow-back that would rate a prior claim on earnings over an integral business cycle.

The effects of plow-back policy upon the market price of the company's stock, and thus upon the firm's cost of capital, must be considered. There is evidence to support the hypothesis that plowing back (as opposed to paying out) earnings depresses the price of a stock and thus raises cost of capital. There is probably an optimum ratio of retained earnings to dividends, since at least some dividend is needed for stockholder peace, while paying all earnings out in dividends connotes impoverished opportunities for internal investment, no plans for growth, and inadequate contingency reserves.

5.4.2 External sources. Historically, the capital markets have not been as large a source of investment funds as have earnings and depreciation charges, but apparently they are not losing their importance. During the 'thirties, when demand for capital was extremely low, new capital issues dropped to 18 per cent of their level during the 'twenties. In the four-year period 1946-1949, net new corporate issues were about one-third the size of retained earnings and depreciation.

Role of cost of capital. When a company considers using outside sources to finance investment, a basic factor is the cost of capital, which for common stock is the ratio of prospective earnings per share to the selling price for new shares. By comparing the company's cost of capital with the prospective profits of new investments, we can measure the gain to present common shares to be derived from going after outside funds. Theoretically, there is no point in going outside unless present equity stands to gain. If a project promising a 25 per cent return is financed by sale of new shares to investors asking a 20 per cent return, the number of outstanding shares will be increased less percentage-wise than total earnings, and per-share earnings on existing shares will increase. But if the return appears to be 15 per cent, the number of shares increases more than total earnings, and per-share earnings fall.

In practice, there are strong qualifications to be considered in using this yardstick, but cost of capital is nevertheless an important guide to capital budgeting, and its level should be known. The problems of measuring it are discussed in financial textbooks.

5.5 CAPITAL RATIONING

We are now ready to put demand and supply together as an economic basis for appraising individual capital expenditure proposals in what may be called capital rationing, the third step in capital budgeting.

5.5.1 Rejection rates. Practical rationing requires not only a ranking of projects according to a ladder of profitability,

but also a rejection rate-of-return standard to separate projects that are not sufficiently profitable to merit funds from those that are. Theoretically, this cut-off rate of return is automatically determined by the intersection of the demand and supply schedules for capital. In practice, however, cut-off rates must be determined by management from the frail information available.

The rejection rate has three uses in administrative control of capital budgeting. The first is to provide a tentative forecast of return expectancies for a next-year budgeting program. In this form, the rejection rate embodies a rough forecast of the demand schedule, and a projected internal supply schedule. Rough as it is, the resulting rejection rate provides some basis for immediate decisions on dividends, financing, and minor capital projects.

The second use of the rejection rate is to weed out projects that have too low a profitability to justify further attention at either divisional or top-management levels. It is thus a tool for economizing executive time.

The third use is to implement a long-run capital-budgeting plan that seeks to avoid making marginal investments of low productivity in times of slack investment demand. In this form, the rejection rate requires, however, a projection for an integral business cycle of both the total demand curve and the total internal supply curve.

Four forms of rejection rate of return can be distinguished: (1) A fluctuating effective rate of return that may move up and down with phases of the business cycle or with cash conditions, and that will determine the cut-off point for normal projects in any one year. (2) A basic minimum rate of earnings that sets a normal floor for any projects in any phase of the business cycle. (3) A stable long-run rate that is frozen as *the* cut-off rate for all phases of the business cycle. (4) Exception rates of return that differ for different kinds of investment to accommodate disparities in risks and the needs of grand strategy.

The effective rate and the minimum rate can be used as a team for short-term budgeting. The long-term rate is an alternative to this team; it is a different system used for coping with cyclical fluctuations. Exception rates can be used in connection with either of these two types of rationing schemes, since such rates may take the form of handicapping differentials.

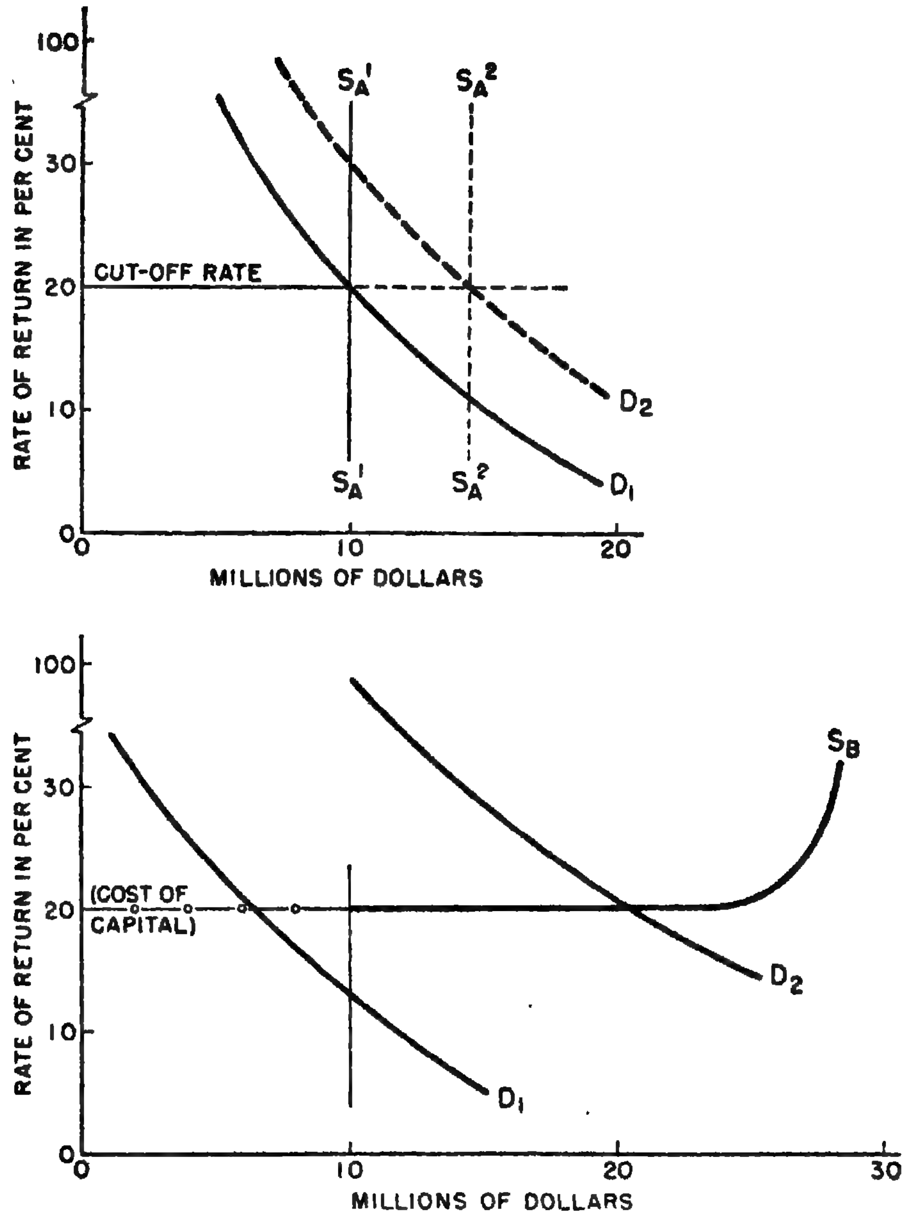
5.5.2 Fluctuating effective rate. In using the effective cut-off rate, two situations must be distinguished: (1) the autonomous firm that is determined to limit itself to internally generated funds only; and (2) the company that is willing to go outside for additional capital funds, either occasionally or regularly. The distinction in the budgeting problem in these two cases stems from the shape and behavior of the supply curves.

Autonomous capital budgeting. The top panel of Fig. 2.9 diagrams the situation for the company that is limited to plow-back earnings for its supply of capital. The demand schedule D_1 portrays for each prospective rate of return the amount of money that the firm can invest internally for earnings of at least that rate. At the point where the curve meets the supply, $S_A{}^1$, this firm can invest \$10,000,000 at a rate of return of 20 per cent or better during the planning period.

The curve D_2 is the demand function in conditions when "needs" for capital expenditures are extremely pressing and profitable, such as in the period immediately following World War II.

The supply curve in this case is the vertical line, $S_1{}^A$. Drawing it as a vertical line emphasizes that, as a practical matter, many companies' internal supply of funds seems to be unrelated to prospective profitability of investments.

Although this theory portrays a company that under no circumstances is willing to use outside money, in practice a cut-off rate that goes much above the costs of capital will act powerfully to undercut this policy and induce the company to engage in some temporary borrowing. How high this rate needs to be to send the company to the banks is a matter of surmise, but it is hard for a company with a 10 per cent cost of capi-



Dean, *Managerial Economics*, p. 590.

FIG. **2.9** THEORY OF CAPITAL RATIONING: FLUCTUATING EFFECTIVE RATE.

tal to reject a 50 per cent rate of return that must be externally financed.

External financing. The lower panel of Fig. 2.9 illustrates the determination of the cut-off rate for a company that is willing to use outside money. In contrast to the autonomous supply case, the supply function extends to the right from the limit of retainable earnings to the point where the market balks at further lending.

Depression shifts of the demand curve to the left that give at cut-off rate less than the cost of capital call for an increased dividend pay-out rather than for the use of funds for submarginal expenditures. As the demand curve shifts to the right, the cut-off rate will remain substantially horizontal to much higher levels of expenditure than most companies have been willing to venture.

A company's cost of capital should, according to this theory, call the signals that regulate supply of funds. When the least profitable investment that can be made from cash generated internally is

below opportunity cost of capital, generous dividends are signaled. Thus cost of capital signals when dividends should restrict internal supply and when and how much recourse should be had to external supply.

5.5.3 Basic minimum rate. An important adjunct to the fluctuating effective cut-off rate is a basic minimum rate below which the effective rate shall not go, no matter how much internal supply exceeds demand for capital. Its purpose is to keep the company from making investments that cannot earn enough to pay their cost of capital. Hence this minimum rate should be set by anticipating future cost of capital.

The company's long-term average rate of earnings on past investment is sometimes set as the basic minimum. This minimum is justified as follows: It represents an earnings rate with which stockholders have been satisfied in the past; it is functionally effective in an economic sense, since it seems to compensate for the risks of the enterprise and to have attracted capital needed for growth.

Sometimes a company goal rate becomes the minimum standard. Some companies have a clear-cut notion of an adequate rate of earnings for the company as a whole. This rate is determined in part by the opportunity to make more than this, and by strategic limitations imposed by considerations of public, political, and labor relations.

5.5.4 The long-run cut-off rate. The third major kind of rejection rate is the long-run rate that cuts across the cyclical swings in earnings prospects and is based on tentative guesses of demand and supply of funds in a five- or ten-year budget. The purpose of this kind of cut-off rate is to avoid having to pass up high-profit projects in times of high demand because funds were squandered on low-return investments in times of low demand. The long-run rate is different from the basic minimum rate both in purpose and in level. The basic minimum serves largely as insurance against major boners in investment, whereas the long-run rate tries to put the next ten years' investment opportunities on a single demand curve to compete for the ten-year supply of funds.

The long-run cut-off rate is useful primarily for decisions on relatively small projects in the immediate future. The rate is established at a top-management level on the basis of quantitative guesses about the major demands for capital foreseeable over the next ten years. It is then passed down the line to middle management as a handy reference point for putting their own immediate projects into the long-run framework. The long-run rate is thus a time-saving device for tying the minor parts into an integrated scheme.

5.5.5 Exception rates. The fourth kind of rejection rate is the special rate that includes a handicap allowance to give strategic investments a head start in the race for capital funds. For example, petroleum companies commonly have a concept of "balanced" investment in production, refining, transportation, and marketing capacities, that overrides profitability criteria on individual projects. A goal of eventually achieving production of 75 per cent of the crude that is marketed may be achieved by assigning well-drilling investments lower cut-off rates than service stations. Similarly, territories where coverage is inadequate or where earnings are below standard may get handicap rates.

Actually, of course, an exception rate is a confession of ignorance—the intangible benefits of such strategic investments are unmeasurable in dollars. The handicap allowance is a guess at the inadequacy of the profit estimate, and, being a guess, has little rational foundation.

5.5.6 Alternatives to rate-of-return rationing. The approach to capital rationing sketched in this section is valid in principle, though limited in applicability. Other methods of capital budgeting can be appraised against this standard of reference.

A common method, which is the antithesis of a rate-of-return system, is to let the determination of the total amount of capital expenditure and its allocation among projects be governed solely by the judgment of top executives who "con-

sider each project on its merits" and tailor the total as best they can to the company's purse. This intuitive approach, when applied in large companies, burdens top management with a multitude of decisions that must be made without objective criteria. Hence the appraisal of an investment proposal is influenced by top management's appraisal of the executive who proposes it, and by his persuasiveness and persistence in presenting it.

Another method widely used in industry is to size up individual investment proposals against an ideal of company balance and growth goals. For example, in the petroleum industry, a company might seek, as a long-run objective, a 50 per cent growth in a decade, and the attainment at the end of ten years of crude-oil production and refining facilities that equal its marketing demand. Such a goal may provide a criterion for approving and rejecting investment proposals, but the effects of this kind of plan upon the company's long-run rate of return are difficult to determine, because this approach views the company as a monolithic strategic investment. "Balance" usually means some form of vertical integration, and vertical integration has not proved universally profitable in all industries, nor is it sure to reduce the hazards of the enterprise.

Paul T. Norton, Jr. is a native of New Jersey, but moved to Philadelphia when twelve years old. After graduating from high school, he worked in various engineering jobs connected with the coal mining industry before deciding to seek an engineering degree. He received his engineering education at the University of Wisconsin, where he earned the Bachelor of Science degree in Electrical Engineering and the degree of Civil Engineer. Coincidentally, he and Eugene L. Grant, co-editor of this *Handbook*, were roommates at Wisconsin.

Upon graduation from the University of Wisconsin, Mr. Norton enlisted in the Army Air Corps and served as an officer in Europe during the latter part of World War I. He returned to civilian life as a sales engineer with The Case Crane and Kilbourne Jacobs Company, Columbus, Ohio, and became vice president of the Company in 1923. He remained in that position until 1926, at which time he joined the Department of Mechanics at the University of Wisconsin.

In 1929, Mr. Norton became the first head of the newly formed Department of Industrial Engineering at the Virginia Polytechnic Institute. He developed that Department into one of the leading ones in the country and remained there until 1948. In 1943, he was granted leave of absence to become Chief of the Industrial Processes Branch of the Office of Production Research and Development, War Production Board. He also served as Treasurer of The Case Crane and Kilbourne Jacobs Company from 1943 until he joined the Company on a full-time basis as vice president in 1948.

Mr. Norton is now a Lecturer in Industrial Engineering at both Stanford University and the University of Florida.

An internationally recognized authority on depreciation and tax problems associated with depreciation matters, Mr. Norton has had published more than 60 papers on various phases of this and related subjects. He also is co-author with Eugene L. Grant of *Depreciation*, a leading text and reference book on this subject. He is a member of American Society of Mechanical Engineers (Chairman, Publications Committee, 1953-1954), American Society for Engineering Education (Council 1934-1937), and American Management Association.

SECTION 3

Engineering Economy

Paul T. Norton, Jr.

1. INTRODUCTION

It would be difficult to exaggerate the economic and social importance of engineering economy. The innumerable decisions that are made each day in this field in private industry determine whether proposals for investment in new plant and equipment are accepted or rejected. These decisions have far-reaching effects on our national standard of living.

It is a truism that a high standard of living depends upon the availability to the average person of an abundance of goods and services, plus the leisure necessary for the enjoyment of these goods and services. It is no accident that those countries possessing the highest degree of mechanization also possess the highest standard of living. Mechanization and the scientific management of our facilities have caused the enormous increase in man-hour productivity in this country.

However, the same mechanization that has made possible a high standard of living has also been the cause of the greatly feared calamity that we call technological unemployment. It is small comfort to the individual worker who has lost his job, or to the community that has lost many jobs through the closing of a factory, to be told that in the long run mechanization has always meant greater total employment. For example, employment in the automobile industry is much greater than it was formerly in spite of the great decrease in the man-hours required to produce an automobile. Moreover, many other jobs in industries would never have developed at all if it had not been for the automobile and the motor truck.

Mechanization that is economically sound will widen markets by reducing the cost of the product, but reduction in total cost can occur only when the saving in operating cost (largely in labor cost) is greater than the increase in fixed charges that almost always follows an increase in mechanization. Since increased mechanization almost always reduces employment per unit of product, it can be justified economically and socially only if total cost, including fixed charges, is really reduced.

A thorough examination of the methods in general use for determining whether it will pay to make investments in productive equipment will prove that many of them contain serious errors in theory. Some of these errors tend to encourage investments that should not be made because they reduce employment without reducing total cost. Other errors tend to prevent investments that really are desirable.

The principal purpose of this section is

to develop methods for use in solving problems in engineering economy. Particular attention is devoted to problems that involve alternatives with differences in such factors as original investments, annual operating expenses, and lives. An attempt is made to introduce briefly the more important problems in this general field, but space limitations prevent the discussion of many problems of considerable importance to certain industries. Readers desiring a fuller discussion of the subject are referred to the bibliography at the end of the section.

1.1 EXPERIENCE AND JUDGMENT ALONE ARE INADEQUATE BASES FOR MANAGEMENT DECISIONS

The great increase in the mechanization of our factories has created many new and serious problems for top management. Insufficient mechanization will often reduce or eliminate profits by making competitive costs impossible to attain, but unwise mechanization will sometimes lead to fixed charges that are excessive and that threaten the financial soundness of the company. Mechanization generally leads to investments that at best cannot be recovered for many years, and that at worst may result in the loss of much of the investment. In addition, a correct decision between alternative ways for providing productive capacity often requires comparisons involving such factors as obsolescence. Where prospective obsolescence seems to be an important danger, it is necessary to weigh the increased chances for profit with a certain investment against the possible greater danger of loss with that particular investment because of rapid obsolescence.

When investments in fixed assets were a small part of the total investment in a business, an experienced manager with good business judgment could safely make decisions without formally considering what we are here calling engineering economy. Today the only safe way to handle alternatives involving investments in plant and equipment is to start with engineering economy studies. Good business judgment and experience are just as valuable as ever, but decisions involving investments in fixed assets should be based as far as possible on the tangible results of engineering economy studies.

1.2 ENGINEERING ECONOMY FORMULAS ARE NOT ALWAYS SAFE

Formulas are useful in the solution of recurrent routine problems because a clerk who does not understand the derivation of a formula can still solve many problems by merely substituting in the formula. However, it should be clearly understood that no formula can be safely used unless someone in the organization understands its derivation and its limitations. Later, in the discussion of the machine replacement problem, it will be pointed out that many replacement formulas containing serious errors in theory have been published year after year for many years past. Other complicated formulas in this field are apparently being used rather extensively by persons who do not fully understand the assumptions on which they are based.

In many phases of engineering economy it is almost impossible to devise a formula that is both sound in principle and also simple in use. Moreover, a common objection to the use of even a sound and simple formula is the fact that it ordinarily gives merely a single value, with little or no information about the effect of even a slight deviation from that value. For example, minimum-cost formulas can often be devised that are both simple and economically sound, but their usefulness is limited by the fact that it is often the minimum-cost range that is really desired rather than the minimum-cost point, which is the only thing the formula can possibly give. What is even more significant, tabular methods that give all the desired information are often as simple and easy to use as the best possible formulas.

Previous generations of industrial managers had an instinctive dislike of formu

las, and it is probable that the unsound machine replacement formulas have done less damage up to now than their prevalence in management books and periodicals would indicate. However, this fortunate condition can hardly be expected to continue; problems have become so complicated that scientific methods are required for their solution, and, in addition, the present generation of industrial managers seem more willing to rely on formulas.

2. EQUIVALENCE

The typical engineering economy problem involves alternatives having differences in such factors as original investment, annual operating expenses, and lives. For example, the alternatives may be machine A, with a first cost of $10,000, annual cash expenditures of $5,000, and an estimated life of 5 years, and machine B, with a first cost of $15,000, annual cash expenditures of $4,000, and an estimated life of 6 years. It is obvious that the data as stated do not furnish sufficient information for comparing the two alternatives. It is necessary to make an economy study in which the first step is to convert the original data to other figures that are *equivalent* to the original data and that are in such shape as to be comparable.

In general, when alternatives such as machines A and B have both initial investments and also cash expenditures spread over the period of the study, all payments must be converted either to an equivalent annual series or to an equivalent single amount at some specific date. In other words, it is necessary either to spread the investment uniformly over the study period and add this amount to the stated annual cash expenditures, or else to convert the annual cash expenditures to a single payment at the time of the investment and add it to the investment. The first method is commonly called the *annual-cost method* and the second method is commonly called the *present-worth method*. Both methods are explained later in this section.

Consider the $10,000 first cost of machine A and the problem of converting this sum of money to a uniform annual figure for 5 years. It would be misleading merely to divide $10,000 by 5 and to assume that a payment of $2,000 a year for 5 years has the same effect as a payment of $10,000 at the start of the 5-year period. Because money has a time value, it is decidedly not a matter of indifference whether $10,000 is spent now or $2,000 is spent each year for 5 years. For equivalence calculations such as the one required to compare machines A and B, it is necessary to select some particular interest rate that seems appropriate for the comparison to be made, all things considered.

Grant describes the concept of equivalence as follows:*

> Given interest rate, we may say that any payment or series of payments which would repay a present sum of money with interest at that rate is equivalent to that present sum. And all future payments or series of payments which would repay the same present sum are equivalent to each other.

2.1 FUNCTION OF INTEREST IN EQUIVALENCE

By means of interest calculations, we can determine an amount at any given time that is equivalent to a stated amount at some other time. For example, if an interest rate of 5 per cent per annum is used, $1.00 now and $1.05 a year from now may be said to be equivalent to each other.

Before attempting to determine an annual amount that is equivalent at 5 per cent per year over a 5-year period to the $10,000 investment in machine A, it is helpful to discuss three plans for the repayment of a loan of $10,000 in 5 years with 5 per cent interest. These plans are shown in Table 3.1. All three are equivalent in the sense that in each plan the borrower pays and the lender

* E. L. Grant, *Principles of Engineering Economy*, 3d ed. (New York: The Ronald Press Company, Inc., 1950), p. 39.

TABLE 3.1 REPAYMENT OF $10,000 IN 5 YEARS WITH INTEREST AT 5 PER CENT

Plan	End of year	Interest due (5% of money owed at start of year)	Total money owed before year-end payment	Year-end payment	Money owed after year-end payment
	0				$10,000.00
	1	$500.00	$10,500.00	$ 500.00	10,000.00
	2	500.00	10,500.00	500.00	10,000.00
1	3	500.00	10,500.00	500.00	10,000.00
	4	500.00	10,500.00	500.00	10,000.00
	5	500.00	10,500.00	10,500.00	0.00
	0				$10,000.00
	1	$500.00	$10,500.00	$2,500.00	8,000.00
	2	400.00	8,400.00	2,400.00	6,000.00
2	3	300.00	6,300.00	2,300.00	4,000.00
	4	200.00	4,200.00	2,200.00	2,000.00
	5	100.00	2,100.00	2,100.00	0.00
	0				$10,000.00
	1	$500.00	$10,500.00	$2,309.75	8,190.25
	2	409.51	8,599.76	2,309.75	6,290.01
3	3	314.50	6,604.51	2,309.75	4,294.76
	4	214.74	4,509.50	2,309.75	2,199.75
	5	109.99	2,309.74	2,309.74	0.00

receives 5 per cent per year on that part of the loan that has not already been repaid.

Table 3.1 shows three popular ways of repaying a $10,000 loan in 5 years, with interest at 5 per cent. In plan 1, the interest is paid at the end of each year, but no part of the principal is repaid until the end of the 5-year period, at which time the entire $10,000 is repaid. In plan 2, one-fifth of the principal is repaid at the end of each year, together with interest on the amount of the unrepaid principal during the year. In plan 3, a uniform amount (partly interest and partly principal) is paid each year, this amount being just large enough so that all the principal, plus interest each year on the unrepaid principal during that year, will be repaid by means of these uniform annual payments of $2,309.75 each. (The determination of the amount of the uniform annual payment will be explained in Art. 3, Compound Interest Factors.)

It will be noted that all three of these methods are equivalent to each other at 5 per cent interest, because in each case the borrower pays back and the lender gets back the principal of the $10,000 loan plus 5 per cent interest each year on the amount of the principal unrepaid during that particular year. These three series of year-end payments are equivalent to each other at 5 per cent, and are also equivalent to $10,000 at the beginning of the 5-year period.

The method of plan 3 is the most useful method in most engineering economy problems, since it makes possible the conversion of a present investment into an equivalent uniform annual cost of capital recovery, plus a return on the investment at the stated interest rate. In other words, if we assume that the $10,000 investment in machine A, described earlier, will be completely dissipated through use in the 5-year period (zero salvage value), the equivalent uniform annual cost of recovering this capital in 5 years, with 5 per cent return on the unrecovered balance during each year, will be $2,309.75 per year. Also the equivalent uniform annual cost of own-

ing and operating this machine will be $7,309.75 per year, the figure that is obtained by adding the annual cash expenditures of $5,000.00 to the capital recovery cost of $2,309.75 per year. It is this equivalent uniform annual cost of $7,309.75 for machine A that we can compare with a similarly obtained cost for machine B, or any other available alternative.

2.2 COMPOUND INTEREST CONCEPT

It can be proved that all methods of repaying the $10,000 in 5 years with 5 per cent interest are equivalent, provided all payments of principal and interest are made at the end of some year and interest is charged each year at 5 per cent on the amount of principal remaining unrepaid during the year. This is true even if no payments of interest or principal are made until the end of the 5-year period. In that case, the interest will be added at the end of each year and in effect will become a part of a new principal. Thus, at the end of the first year, the interest will be $500, and when this is added to the original $10,000 principal, the principal during the second year becomes $10,500, and the interest at the end of the second year will be $525. Interest will be $551.25, $578.81, and $607.75 respectively in the third, fourth, and fifth years, and the amount to be repaid at the end of the fifth year will be $12,762.81. It will be recognized that this particular method employs the compounding of interest rather than the actual payment each year of the interest due.

It can easily be shown that the compound interest concept is the proper one for business loans and investments no matter how loans are repaid or investments recovered. This is true in actual loans from the viewpoint of both the borrower and the lender. Where interest is actually paid at the end of each interest period, it may be assumed that the lender could invest this amount and receive interest on it and also that the borrower could have invested the interest he actually paid if he had not paid it when he did.

It has been simpler to introduce the concept of equivalence by the use of a $10,000 loan for 5 years with 5 per cent interest, but in engineering economy most of the problems involve investments which it is hoped will be productive enough so that the amount of the investment will be recovered plus a satisfactory return. Much of the remainder of this section will be devoted to examples in which these investments will be converted into equivalent uniform annual costs of capital recovery. These conversions will utilize compound interest factors in what may be called the basic (or accurate) procedure, although in some cases an approximate method called the straight-line depreciation and average interest method will be used.

Although the basic concept involved in the recovery of an investment (capital recovery with a return) is the same as that developed previously in this section for the repayment of a loan, the recovery of an investment in such things as plant and equipment is quite independent of the source of the funds that were used. The source and availability of investment funds may properly be considered when deciding whether certain types of investment should be made and in such matters as the setting of minimum attractive rates of return (interest rates). But care must be taken not to confuse the recovery of an investment with the repayment of a loan.

3. COMPOUND INTEREST FACTORS

The compound interest factors discussed in this article provide a convenient means for converting a single payment at some particular time into an equivalent single payment at some other time, or of converting a single payment at some particular time into an equivalent uniform series of payments, or of converting a uniform series of payments into an equivalent single payment at some particular time. By the use of two or more of these factors, vari-

TABLE 3.2 2 PER CENT COMPOUND INTEREST FACTORS*

n	Single payment		Uniform payment series				n
	Compound-amount factor	Present-worth factor	Compound-amount factor	Sinking-fund factor	Present-worth factor	Capital-recovery factor	
	Given P to find S $(1+i)^n$	Given S to find P $\frac{1}{(1+i)^n}$	Given R to find S $\frac{(1+i)^n-1}{i}$	Given S to find R $\frac{i}{(1+i)^n-1}$	Given R to find P $\frac{(1+i)^n-1}{i(1+i)^n}$	Given P to find R $\frac{i(1+i)^n}{(1+i)^n-1}$	
1	1.020	0.9804	1.000	1.00000	0.980	1.02000	**1**
2	1.040	0.9612	2.020	0.49505	1.942	0.51505	**2**
3	1.061	0.9423	3.060	0.32675	2.884	0.34675	**3**
4	1.082	0.9238	4.122	0.24262	3.808	0.26262	**4**
5	1.104	0.9057	5.204	0.19216	4.713	0.21216	**5**
6	1.126	0.8880	6.308	0.15853	5.601	0.17853	**6**
7	1.149	0.8706	7.434	0.13451	6.472	0.15451	**7**
8	1.172	0.8535	8.583	0.11651	7.325	0.13651	**8**
9	1.195	0.8368	9.755	0.10252	8.162	0.12252	**9**
10	1.219	0.8203	10.950	0.09133	8.983	0.11133	**10**
11	1.243	0.8043	12.169	0.08218	9.787	0.10218	**11**
12	1.268	0.7885	13.412	0.07456	10.575	0.09456	**12**
13	1.294	0.7730	14.680	0.06812	11.348	0.08812	**13**
14	1.319	0.7579	15.974	0.06260	12.106	0.08260	**14**
15	1.346	0.7430	17.293	0.05783	12.849	0.07783	**15**
16	1.373	0.7284	18.639	0.05365	13.578	0.07365	**16**
17	1.400	0.7142	20.012	0.04997	14.292	0.06997	**17**
18	1.428	0.7002	21.412	0.04670	14.992	0.06670	**18**
19	1.457	0.6864	22.841	0.04378	15.678	0.06378	**19**
20	1.486	0.6730	24.297	0.04116	16.351	0.06116	**20**
21	1.516	0.6598	25.783	0.03878	17.011	0.05878	**21**
22	1.546	0.6468	27.299	0.03663	17.658	0.05663	**22**
23	1.577	0.6342	28.845	0.03467	18.292	0.05467	**23**
24	1.608	0.6217	30.422	0.03287	18.914	0.05287	**24**
25	1.641	0.6095	32.030	0.03122	19.523	0.05122	**25**
26	1.673	0.5976	33.671	0.02970	20.121	0.04970	**26**
27	1.707	0.5859	35.344	0.02829	20.707	0.04829	**27**
28	1.741	0.5744	37.051	0.02699	21.281	0.04699	**28**
29	1.776	0.5631	38.792	0.02578	21.844	0.04578	**29**
30	1.811	0.5521	40.568	0.02465	22.396	0.04465	**30**
31	1.848	0.5412	42.379	0.02360	22.938	0.04360	**31**
32	1.885	0.5306	44.227	0.02261	23.468	0.04261	**32**
33	1.922	0.5202	46.112	0.02169	23.989	0.04169	**33**
34	1.961	0.5100	48.034	0.02082	24.499	0.04082	**34**
35	2.000	0.5000	49.994	0.02000	24.999	0.04000	**35**
40	2.208	0.4529	60.402	0.01656	27.355	0.03656	**40**
45	2.438	0.4102	71.893	0.01391	29.490	0.03391	**45**
50	2.692	0.3715	84.579	0.01182	31.424	0.03182	**50**
55	2.972	0.3365	98.587	0.01014	33.175	0.03014	**55**
60	3.281	0.3048	114.052	0.00877	34.761	0.02877	**60**
65	3.623	0.2761	131.126	0.00763	36.197	0.02763	**65**
70	4.000	0.2500	149.978	0.00667	37.499	0.02667	**70**
75	4.416	0.2265	170.792	0.00586	38.677	0.02586	**75**
80	4.875	0.2051	193.772	0.00516	39.745	0.02516	**80**
85	5.383	0.1858	219.144	0.00456	40.711	0.02456	**85**
90	5.943	0.1683	247.157	0.00405	41.587	0.02405	**90**
95	6.562	0.1524	278.085	0.00360	42.380	0.02360	**95**
100	7.245	0.1380	312.232	0.00320	43.098	0.02320	**100**

* Tables 3.2 to 3.10 from H. G. Thuesen, *Engineering Economy*, Copyright, 1950, by Prentice-Hall, Inc., New York, pp. 483-490, 491.

ing and operating this machine will be \$7,309.75 per year, the figure that is obtained by adding the annual cash expenditures of \$5,000.00 to the capital recovery cost of \$2,309.75 per year. It is this equivalent uniform annual cost of \$7,309.75 for machine A that we can compare with a similarly obtained cost for machine B, or any other available alternative.

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It can be proved that all methods of repaying the \$10,000 in 5 years with 5 per cent interest are equivalent, provided all payments of principal and interest are made at the end of some year and interest is charged each year at 5 per cent on the amount of principal remaining unrepaid during the year. This is true even if no payments of interest or principal are made until the end of the 5-year period. In that case, the interest will be added at the end of each year and in effect will become a part of a new principal. Thus, at the end of the first year, the interest will be \$500, and when this is added to the original \$10,000 principal, the principal during the second year becomes \$10,500, and the interest at the end of the second year will be \$525. Interest will be \$551.25, \$578.81, and \$607.75 respectively in the third, fourth, and fifth years, and the amount to be repaid at the end of the fifth year will be \$12,762.81. It will be recognized that this particular method employs the compounding of interest rather than the actual payment each year of the interest due.

It can easily be shown that the compound interest concept is the proper one for business loans and investments no matter how loans are repaid or investments recovered. This is true in actual loans from the viewpoint of both the borrower and the lender. Where interest is actually paid at the end of each interest period, it may be assumed that the lender could invest this amount and receive interest on it and also that the borrower could have invested the interest he actually paid if he had not paid it when he did.

It has been simpler to introduce the concept of equivalence by the use of a \$10,000 loan for 5 years with 5 per cent interest, but in engineering economy most of the problems involve investments which it is hoped will be productive enough so that the amount of the investment will be recovered plus a satisfactory return. Much of the remainder of this section will be devoted to examples in which these investments will be converted into equivalent uniform annual costs of capital recovery. These conversions will utilize compound interest factors in what may be called the basic (or accurate) procedure, although in some cases an approximate method called the straight-line depreciation and average interest method will be used.

Although the basic concept involved in the recovery of an investment (capital recovery with a return) is the same as that developed previously in this section for the repayment of a loan, the recovery of an investment in such things as plant and equipment is quite independent of the source of the funds that were used. The source and availability of investment funds may properly be considered when deciding whether certain types of investment should be made and in such matters as the setting of minimum attractive rates of return (interest rates). But care must be taken not to confuse the recovery of an investment with the repayment of a loan.

3. COMPOUND INTEREST FACTORS

The compound interest factors discussed in this article provide a convenient means for converting a single payment at some particular time into an equivalent single payment at some other time, or of converting a single payment at some particular time into an equivalent uniform series of payments, or of converting a uniform series of payments into an equivalent single payment at some particular time. By the use of two or more of these factors, vari-

TABLE 3.2 2 PER CENT COMPOUND INTEREST FACTORS*

n	Single payment		Uniform payment series				n
	Compound-amount factor	Present-worth factor	Compound-amount factor	Sinking-fund factor	Present-worth factor	Capital-recovery factor	
	Given P to find S $(1+i)^n$	Given S to find P $\frac{1}{(1+i)^n}$	Given R to find S $\frac{(1+i)^n-1}{i}$	Given S to find R $\frac{i}{(1+i)^n-1}$	Given R to find P $\frac{(1+i)^n-1}{i(1+i)^n}$	Given P to find R $\frac{i(1+i)^n}{(1+i)^n-1}$	
1	1.020	0.9804	1.000	1.00000	0.980	1.02000	**1**
2	1.040	0.9612	2.020	0.49505	1.942	0.51505	**2**
3	1.061	0.9423	3.060	0.32675	2.884	0.34675	**3**
4	1.082	0.9238	4.122	0.24262	3.808	0.26262	**4**
5	1.104	0.9057	5.204	0.19216	4.713	0.21216	**5**
6	1.126	0.8880	6.308	0.15853	5.601	0.17853	**6**
7	1.149	0.8706	7.434	0.13451	6.472	0.15451	**7**
8	1.172	0.8535	8.583	0.11651	7.325	0.13651	**8**
9	1.195	0.8368	9.755	0.10252	8.162	0.12252	**9**
10	1.219	0.8203	10.950	0.09133	8.983	0.11133	**10**
11	1.243	0.8043	12.169	0.08218	9.787	0.10218	**11**
12	1.268	0.7885	13.412	0.07456	10.575	0.09456	**12**
13	1.294	0.7730	14.680	0.06812	11.348	0.08812	**13**
14	1.319	0.7579	15.974	0.06260	12.106	0.08260	**14**
15	1.346	0.7430	17.293	0.05783	12.849	0.07783	**15**
16	1.373	0.7284	18.639	0.05365	13.578	0.07365	**16**
17	1.400	0.7142	20.012	0.04997	14.292	0.06997	**17**
18	1.428	0.7002	21.412	0.04670	14.992	0.06670	**18**
19	1.457	0.6864	22.841	0.04378	15.678	0.06378	**19**
20	1.486	0.6730	24.297	0.04116	16.351	0.06116	**20**
21	1.516	0.6598	25.783	0.03878	17.011	0.05878	**21**
22	1.546	0.6468	27.299	0.03663	17.658	0.05663	**22**
23	1.577	0.6342	28.845	0.03467	18.292	0.05467	**23**
24	1.608	0.6217	30.422	0.03287	18.914	0.05287	**24**
25	1.641	0.6095	32.030	0.03122	19.523	0.05122	**25**
26	1.673	0.5976	33.671	0.02970	20.121	0.04970	**26**
27	1.707	0.5859	35.344	0.02829	20.707	0.04829	**27**
28	1.741	0.5744	37.051	0.02699	21.281	0.04699	**28**
29	1.776	0.5631	38.792	0.02578	21.844	0.04578	**29**
30	1.811	0.5521	40.568	0.02465	22.396	0.04465	**30**
31	1.848	0.5412	42.379	0.02360	22.938	0.04360	**31**
32	1.885	0.5306	44.227	0.02261	23.468	0.04261	**32**
33	1.922	0.5202	46.112	0.02169	23.989	0.04169	**33**
34	1.961	0.5100	48.034	0.02082	24.499	0.04082	**34**
35	2.000	0.5000	49.994	0.02000	24.999	0.04000	**35**
40	2.208	0.4529	60.402	0.01656	27.355	0.03656	**40**
45	2.438	0.4102	71.893	0.01391	29.490	0.03391	**45**
50	2.692	0.3715	84.579	0.01182	31.424	0.03182	**50**
55	2.972	0.3365	98.587	0.01014	33.175	0.03014	**55**
60	3.281	0.3048	114.052	0.00877	34.761	0.02877	**60**
65	3.623	0.2761	131.126	0.00763	36.197	0.02763	**65**
70	4.000	0.2500	149.978	0.00667	37.499	0.02667	**70**
75	4.416	0.2265	170.792	0.00586	38.677	0.02586	**75**
80	4.875	0.2051	193.772	0.00516	39.745	0.02516	**80**
85	5.383	0.1858	219.144	0.00456	40.711	0.02456	**85**
90	5.943	0.1683	247.157	0.00405	41.587	0.02405	**90**
95	6.562	0.1524	278.085	0.00360	42.380	0.02360	**95**
100	7.245	0.1380	312.232	0.00320	43.098	0.02320	**100**

* Tables 3.2 to 3.10 from H. G. Thuesen, *Engineering Economy*. Copyright, 1950, by Prentice-Hall, Inc., New York, pp. 483-490, 491.

TABLE **3.3** 3 PER CENT COMPOUND INTEREST FACTORS

n	Single payment		Uniform payment series				n
	Compound-amount factor	Present-worth factor	Compound-amount factor	Sinking-fund factor	Present-worth factor	Capital-recovery factor	
	Given P to find S $(1+i)^n$	Given S to find P $\frac{1}{(1+i)^n}$	Given R to find S $\frac{(1+i)^n - 1}{i}$	Given S to find R $\frac{i}{(1+i)^n - 1}$	Given R to find P $\frac{(1+i)^n - 1}{i(1+i)^n}$	Given P to find R $\frac{i(1+i)^n}{(1+i)^n - 1}$	
1	1.030	0.9709	1.000	1.00000	0.971	1.03000	**1**
2	1.061	0.9426	2.030	0.49261	1.913	0.52261	**2**
3	1.093	0.9151	3.091	0.32353	2.829	0.35353	**3**
4	1.126	0.8885	4.184	0.23903	3.717	0.26903	**4**
5	1.159	0.8626	5.309	0.18835	4.580	0.21835	**5**
6	1.194	0.8375	6.468	0.15460	5.417	0.18460	**6**
7	1.230	0.8131	7.662	0.13051	6.230	0.16051	**7**
8	1.267	0.7894	8.892	0.11246	7.020	0.14246	**8**
9	1.305	0.7664	10.159	0.09843	7.786	0.12843	**9**
10	1.344	0.7441	11.464	0.08723	8.530	0.11723	**10**
11	1.384	0.7224	12.808	0.07808	9.253	0.10808	**11**
12	1.426	0.7014	14.192	0.07046	9.954	0.10046	**12**
13	1.469	0.6810	15.618	0.06403	10.635	0.09403	**13**
14	1.513	0.6611	17.086	0.05853	11.296	0.08853	**14**
15	1.558	0.6419	18.599	0.05377	11.938	0.08377	**15**
16	1.605	0.6232	20.157	0.04961	12.561	0.07961	**16**
17	1.653	0.6050	21.762	0.04595	13.166	0.07595	**17**
18	1.702	0.5874	23.414	0.04271	13.754	0.07271	**18**
19	1.754	0.5703	25.117	0.03981	14.324	0.06981	**19**
20	1.806	0.5537	26.870	0.03722	14.877	0.06722	**20**
21	1.860	0.5375	28.676	0.03487	15.415	0.06487	**21**
22	1.916	0.5219	30.537	0.03275	15.937	0.06275	**22**
23	1.974	0.5067	32.453	0.03081	16.444	0.06081	**23**
24	2.033	0.4919	34.426	0.02905	16.936	0.05905	**24**
25	2.094	0.4776	36.459	0.02743	17.413	0.05743	**25**
26	2.157	0.4637	38.553	0.02594	17.877	0.05594	**26**
27	2.221	0.4502	40.710	0.02456	18.327	0.05456	**27**
28	2.288	0.4371	42.931	0.02329	18.764	0.05329	**28**
29	2.357	0.4243	45.219	0.02211	19.188	0.05211	**29**
30	2.427	0.4120	47.575	0.02102	19.600	0.05102	**30**
31	2.500	0.4000	50.003	0.02000	20.000	0.05000	**31**
32	2.575	0.3883	52.503	0.01905	20.389	0.04905	**32**
33	2.652	0.3770	55.078	0.01816	20.766	0.04816	**33**
34	2.732	0.3660	57.730	0.01732	21.132	0.04732	**34**
35	2.814	0.3554	60.462	0.01654	21.487	0.04654	**35**
40	3.262	0.3066	75.401	0.01326	23.115	0.04326	**40**
45	3.782	0.2644	92.720	0.01079	24.519	0.04079	**45**
50	4.384	0.2281	112.797	0.00887	25.730	0.03887	**50**
55	5.082	0.1968	136.072	0.00735	26.774	0.03735	**55**
60	5.892	0.1697	163.053	0.00613	27.676	0.03613	**60**
65	6.830	0.1464	194.333	0.00515	28.453	0.03515	**65**
70	7.918	0.1263	230.594	0.00434	29.123	0.03434	**70**
75	9.179	0.1089	272.631	0.00367	29.702	0.03367	**75**
80	10.641	0.0940	321.363	0.00311	30.201	0.03311	**80**
85	12.336	0.0811	377.857	0.00265	30.631	0.03265	**85**
90	14.300	0.0699	443.349	0.00226	31.002	0.03226	**90**
95	16.578	0.0603	519.272	0.00193	31.323	0.03193	**95**
100	19.219	0.0520	607.288	0.00165	31.599	0.03165	**100**

TABLE 3.4 4 PER CENT COMPOUND INTEREST FACTORS

n	Single payment: Compound-amount factor, Given P to find S, $(1+i)^n$	Single payment: Present-worth factor, Given S to find P, $\frac{1}{(1+i)^n}$	Uniform payment series: Compound-amount factor, Given R to find S, $\frac{(1+i)^n-1}{i}$	Uniform payment series: Sinking-fund factor, Given S to find R, $\frac{i}{(1+i)^n-1}$	Uniform payment series: Present-worth factor, Given R to find P, $\frac{(1+i)^n-1}{i(1+i)^n}$	Uniform payment series: Capital-recovery factor, Given P to find R, $\frac{i(1+i)^n}{(1+i)^n-1}$	n
1	1.040	0.9615	1.000	1.00000	0.962	1.04000	1
2	1.082	0.9246	2.040	0.49020	1.886	0.53020	2
3	1.125	0.8890	3.122	0.32035	2.775	0.36035	3
4	1.170	0.8548	4.246	0.23549	3.630	0.27549	4
5	1.217	0.8219	5.416	0.18463	4.452	0.22463	5
6	1.265	0.7903	6.633	0.15076	5.242	0.19076	6
7	1.316	0.7599	7.898	0.12661	6.002	0.16661	7
8	1.369	0.7307	9.214	0.10853	6.733	0.14853	8
9	1.423	0.7026	10.583	0.09449	7.435	0.13449	9
10	1.480	0.6756	12.006	0.08329	8.111	0.12329	10
11	1.539	0.6496	13.486	0.07415	8.760	0.11415	11
12	1.601	0.6246	15.026	0.06655	9.385	0.10655	12
13	1.665	0.6006	16.627	0.06014	9.986	0.10014	13
14	1.732	0.5775	18.292	0.05467	10.563	0.09467	14
15	1.801	0.5553	20.024	0.04994	11.118	0.08994	15
16	1.873	0.5339	21.825	0.04582	11.652	0.08582	16
17	1.948	0.5134	23.698	0.04220	12.166	0.08220	17
18	2.026	0.4936	25.645	0.03899	12.659	0.07899	18
19	2.107	0.4746	27.671	0.03614	13.134	0.07614	19
20	2.191	0.4564	29.778	0.03358	13.590	0.07358	20
21	2.279	0.4388	31.969	0.03128	14.029	0.07128	21
22	2.370	0.4220	34.248	0.02920	14.451	0.06920	22
23	2.465	0.4057	36.618	0.02731	14.857	0.06731	23
24	2.563	0.3901	39.083	0.02559	15.247	0.06559	24
25	2.666	0.3751	41.646	0.02401	15.622	0.06401	25
26	2.772	0.3607	44.312	0.02257	15.983	0.06257	26
27	2.883	0.3468	47.084	0.02124	16.330	0.06124	27
28	2.999	0.3335	49.968	0.02001	16.663	0.06001	28
29	3.119	0.3207	52.966	0.01888	16.984	0.05888	29
30	3.243	0.3083	56.085	0.01783	17.292	0.05783	30
31	3.373	0.2965	59.328	0.01686	17.588	0.05686	31
32	3.508	0.2851	62.701	0.01595	17.874	0.05595	32
33	3.648	0.2741	66.210	0.01510	18.148	0.05510	33
34	3.794	0.2636	69.858	0.01431	18.411	0.05431	34
35	3.946	0.2534	73.652	0.01358	18.665	0.05358	35
40	4.801	0.2083	95.026	0.01052	19.793	0.05052	40
45	5.841	0.1712	121.029	0.00826	20.720	0.04826	45
50	7.107	0.1407	152.667	0.00655	21.482	0.04655	50
55	8.646	0.1157	191.159	0.00523	22.109	0.04523	55
60	10.520	0.0951	237.991	0.00420	22.623	0.04420	60
65	12.799	0.0781	294.968	0.00339	23.047	0.04339	65
70	15.572	0.0642	364.290	0.00275	23.395	0.04275	70
75	18.945	0.0528	448.631	0.00223	23.680	0.04223	75
80	23.050	0.0434	551.245	0.00181	23.915	0.04181	80
85	28.044	0.0357	676.090	0.00148	24.109	0.04148	85
90	34.119	0.0293	827.983	0.00121	24.267	0.04121	90
95	41.511	0.0241	1012.785	0.00099	24.398	0.04099	95
100	50.505	0.0198	1237.624	0.00081	24.505	0.04081	100

TABLE 3.5 5 PER CENT COMPOUND INTEREST FACTORS

n	Single payment: Compound-amount factor, Given P to find S, $(1+i)^n$	Single payment: Present-worth factor, Given S to find P, $\frac{1}{(1+i)^n}$	Uniform payment series: Compound-amount factor, Given R to find S, $\frac{(1+i)^n-1}{i}$	Uniform payment series: Sinking-fund factor, Given S to find R, $\frac{i}{(1+i)^n-1}$	Uniform payment series: Present-worth factor, Given R to find P, $\frac{(1+i)^n-1}{i(1+i)^n}$	Uniform payment series: Capital-recovery factor, Given P to find R, $\frac{i(1+i)^n}{(1+i)^n-1}$	n
1	1.050	0.9524	1.000	1.00000	0.952	1.05000	**1**
2	1.103	0.9070	2.050	0.48780	1.859	0.53780	**2**
3	1.158	0.8638	3.153	0.31721	2.723	0.36721	**3**
4	1.216	0.8227	4.310	0.23201	3.546	0.28201	**4**
5	1.276	0.7835	5.526	0.18097	4.329	0.23097	**5**
6	1.340	0.7462	6.802	0.14702	5.076	0.19702	**6**
7	1.407	0.7107	8.142	0.12282	5.786	0.17282	**7**
8	1.477	0.6768	9.549	0.10472	6.463	0.15472	**8**
9	1.551	0.6446	11.027	0.09069	7.108	0.14069	**9**
10	1.629	0.6139	12.57	0.07950	7.722	0.12950	**10**
11	1.710	0.5847	14.207	0.07039	8.306	0.12039	**11**
12	1.796	0.5568	15.917	0.06283	8.863	0.11283	**12**
13	1.886	0.5303	17.713	0.05646	9.394	0.10646	**13**
14	1.980	0.5051	19.599	0.05102	9.899	0.10102	**14**
15	2.079	0.4810	21.579	0.04634	10.380	0.09634	**15**
16	2.183	0.4581	23.657	0.04227	10.838	0.09227	**16**
17	2.292	0.4363	25.840	0.03870	11.274	0.08870	**17**
18	2.407	0.4155	28.132	0.03555	11.690	0.08555	**18**
19	2.527	0.3957	30.539	0.03275	12.085	0.08275	**19**
20	2.653	0.3769	33.066	0.03024	12.462	0.08024	**20**
21	2.786	0.3589	35.719	0.02800	12.821	0.07800	**21**
22	2.925	0.3418	38.505	0.02597	13.163	0.07597	**22**
23	3.072	0.3256	41.430	0.02414	13.489	0.07414	**23**
24	3.225	0.3101	44.502	0.02247	13.799	0.07247	**24**
25	3.386	0.2953	47.727	0.02095	14.094	0.07095	**25**
26	3.556	0.2812	51.113	0.01956	14.375	0.06956	**26**
27	3.733	0.2678	54.669	0.01829	14.643	0.06829	**27**
28	3.920	0.2551	58.403	0.01712	14.898	0.06712	**28**
29	4.116	0.2429	62.323	0.01605	15.141	0.06605	**29**
30	4.322	0.2314	66.439	0.01505	15.372	0.06505	**30**
31	4.538	0.2204	70.761	0.01413	15.593	0.06413	**31**
32	4.765	0.2099	75.299	0.01328	15.803	0.06328	**32**
33	5.003	0.1999	80.064	0.01249	16.003	0.06249	**33**
34	5.253	0.1904	85.067	0.01176	16.193	0.06176	**34**
35	5.516	0.1813	90.320	0.01107	16.374	0.06107	**35**
40	7.040	0.1420	120.800	0.00828	17.159	0.05828	**40**
45	8.985	0.1113	159.700	0.00626	17.774	0.05626	**45**
50	11.467	0.0872	209.348	0.00478	18.256	0.05478	**50**
55	14.636	0.0683	272.713	0.00367	18.633	0.05367	**55**
60	18.679	0.0535	353.584	0.00283	18.929	0.05283	**60**
65	23.840	0.0419	456.798	0.00219	19.161	0.05219	**65**
70	30.426	0.0329	588.529	0.00170	19.343	0.05170	**70**
75	38.833	0.0258	756.654	0.00132	19.485	0.05132	**75**
80	49.561	0.0202	971.229	0.00103	19.596	0.05103	**80**
85	63.254	0.0158	1215.087	0.00080	19.684	0.05080	**85**
90	80.730	0.0124	1594.607	0.00063	19.752	0.05063	**90**
95	103.035	0.0097	2040.694	0.00049	19.806	0.05049	**95**
100	131.501	0.0076	2610.025	0.00038	19.848	0.05038	**100**

TABLE 3.6 6 PER CENT COMPOUND INTEREST FACTORS

n	Single payment: Compound-amount factor	Single payment: Present-worth factor	Uniform payment series: Compound-amount factor	Uniform payment series: Sinking-fund factor	Uniform payment series: Present-worth factor	Uniform payment series: Capital-recovery factor	n
	Given P to find S $(1+i)^n$	Given S to find P $\frac{1}{(1+i)^n}$	Given R to find S $\frac{(1+i)^n-1}{i}$	Given S to find R $\frac{i}{(1+i)^n-1}$	Given R to find P $\frac{(1+i)^n-1}{i(1+i)^n}$	Given P to find R $\frac{i(1+i)^n}{(1+i)^n-1}$	
1	1.060	0.9434	1.000	1.00000	0.943	1.06000	**1**
2	1.124	0.8900	2.060	0.48544	1.833	0.54544	**2**
3	1.191	0.8396	3.184	0.31411	2.673	0.37411	**3**
4	1.262	0.7921	4.375	0.22859	3.465	0.28859	**4**
5	1.338	0.7473	5.637	0.17740	4.212	0.23740	**5**
6	1.419	0.7050	6.975	0.14336	4.917	0.20336	**6**
7	1.504	0.6651	8.394	0.11914	5.582	0.17914	**7**
8	1.594	0.6274	9.897	0.10104	6.210	0.16104	**8**
9	1.689	0.5919	11.491	0.08702	6.802	0.14702	**9**
10	1.791	0.5584	13.181	0.07587	7.360	0.13587	**10**
11	1.898	0.5268	14.972	0.06679	7.887	0.12679	**11**
12	2.012	0.4970	16.870	0.05928	8.384	0.11928	**12**
13	2.133	0.4688	18.882	0.05296	8.853	0.11296	**13**
14	2.261	0.4423	21.015	0.04758	9.295	0.10758	**14**
15	2.397	0.4173	23.276	0.04296	9.712	0.10296	**15**
16	2.540	0.3936	25.673	0.03895	10.106	0.09895	**16**
17	2.693	0.3714	28.213	0.03544	10.477	0.09544	**17**
18	2.854	0.3503	30.906	0.03236	10.828	0.09236	**18**
19	3.026	0.3305	33.760	0.02962	11.158	0.08962	**19**
20	3.207	0.3118	36.786	0.02718	11.470	0.08718	**20**
21	3.400	0.2942	39.993	0.02500	11.764	0.08500	**21**
22	3.604	0.2775	43.392	0.02305	12.042	0.08305	**22**
23	3.820	0.2618	46.996	0.02128	12.303	0.08128	**23**
24	4.049	0.2470	50.816	0.01968	12.550	0.07968	**24**
25	4.292	0.2330	54.865	0.01823	12.783	0.07823	**25**
26	4.549	0.2198	59.156	0.01690	13.003	0.07690	**26**
27	4.822	0.2074	63.706	0.01570	13.211	0.07570	**27**
28	5.112	0.1956	68.528	0.01459	13.406	0.07459	**28**
29	5.418	0.1846	73.640	0.01358	13.591	0.07358	**29**
30	5.743	0.1741	79.058	0.01265	13.765	0.07265	**30**
31	6.088	0.1643	84.802	0.01179	13.929	0.07179	**31**
32	6.453	0.1550	90.890	0.01100	14.084	0.07100	**32**
33	6.841	0.1462	97.343	0.01027	14.230	0.07027	**33**
34	7.251	0.1379	104.184	0.00960	14.368	0.06960	**34**
35	7.686	0.1301	111.435	0.00897	14.498	0.06897	**35**
40	10.286	0.0972	154.762	0.00646	15.046	0.06646	**40**
45	13.765	0.0727	212.744	0.00470	15.456	0.06470	**45**
50	18.420	0.0543	290.336	0.00344	15.762	0.06344	**50**
55	24.650	0.0406	394.172	0.00254	15.991	0.06254	**55**
60	32.988	0.0303	533.128	0.00188	16.161	0.06188	**60**
65	44.145	0.0227	719.083	0.00139	16.289	0.06139	**65**
70	59.076	0.0169	967.932	0.00103	16.385	0.06103	**70**
75	79.057	0.0126	1300.949	0.00077	16.456	0.06077	**75**
80	105.796	0.0095	1746.600	0.00057	16.509	0.06057	**80**
85	141.579	0.0071	2342.982	0.00043	16.549	0.06043	**85**
90	189.465	0.0053	3141.075	0.00032	16.579	0.06032	**90**
95	253.546	0.0039	4209.104	0.00024	16.601	0.06024	**95**
100	339.302	0.0029	5638.368	0.00018	16.618	0.06018	**100**

TABLE 3.7 7 PER CENT COMPOUND INTEREST FACTORS

	Single payment		Uniform payment series				
n	Compound-amount factor Given P to find S $(1+i)^n$	Present-worth factor Given S to find P $\frac{1}{(1+i)^n}$	Compound-amount factor Given R to find S $\frac{(1+i)^n-1}{i}$	Sinking-fund factor Given S to find R $\frac{i}{(1+i)^n-1}$	Present-worth factor Given R to find P $\frac{(1+i)^n-1}{i(1+i)^n}$	Capital-recovery factor Given P to find R $\frac{i(1+i)^n}{(1+i)^n-1}$	n
1	1.070	0.9346	1.000	1.00000	0.935	1.07000	**1**
2	1.145	0.8734	2.070	0.48309	1.808	0.55309	**2**
3	1.225	0.8163	3.215	0.31105	2.624	0.38105	**3**
4	1.311	0.7629	4.440	0.22523	3.387	0.29523	**4**
5	1.403	0.7130	5.751	0.17389	4.100	0.24389	**5**
6	1.501	0.6663	7.153	0.13980	4.767	0.20980	**6**
7	1.606	0.6227	8.654	0.11555	5.389	0.18555	**7**
8	1.718	0.5820	10.260	0.09747	5.971	0.16747	**8**
9	1.838	0.5439	11.978	0.08349	6.515	0.15349	**9**
10	1.967	0.5083	13.816	0.07238	7.024	0.14238	**10**
11	2.105	0.4751	15.784	0.06336	7.499	0.13336	**11**
12	2.252	0.4440	17.888	0.05590	7.943	0.12590	**12**
13	2.410	0.4150	20.141	0.04965	8.358	0.11965	**13**
14	2.579	0.3878	22.550	0.04434	8.745	0.11434	**14**
15	2.759	0.3624	25.129	0.03979	9.108	0.10979	**15**
16	2.952	0.3387	27.888	0.03586	9.447	0.10586	**16**
17	3.159	0.3166	30.840	0.03243	9.763	0.10243	**17**
18	3.380	0.2959	33.999	0.02941	10.059	0.09941	**18**
19	3.617	0.2765	37.379	0.02675	10.336	0.09675	**19**
20	3.870	0.2584	40.995	0.02439	10.594	0.09439	**20**
21	4.141	0.2415	44.865	0.02229	10.836	0.09229	**21**
22	4.430	0.2257	49.006	0.02041	11.061	0.09041	**22**
23	4.741	0.2109	53.436	0.01871	11.272	0.08871	**23**
24	5.072	0.1971	58.177	0.01719	11.469	0.08719	**24**
25	5.427	0.1842	63.249	0.01581	11.654	0.08581	**25**
26	5.807	0.1722	68.676	0.01456	11.826	0.08456	**26**
27	6.214	0.1609	74.484	0.01343	11.987	0.08343	**27**
28	6.649	0.1504	80.698	0.01239	12.137	0.08239	**28**
29	7.114	0.1406	87.347	0.01145	12.278	0.08145	**29**
30	7.612	0.1314	94.461	0.01059	12.409	0.08059	**30**
31	8.145	0.1228	102.073	0.00980	12.532	0.07980	**31**
32	8.715	0.1147	110.218	0.00907	12.647	0.07907	**32**
33	9.325	0.1072	118.933	0.00841	12.754	0.07841	**33**
34	9.978	0.1002	128.259	0.00780	12.854	0.07780	**34**
35	10.677	0.0937	138.237	0.00723	12.948	0.07723	**35**
40	14.974	0.0668	199.635	0.00501	13.332	0.07501	**40**
45	21.002	0.0476	285.749	0.00350	13.606	0.07350	**45**
50	29.457	0.0339	406.529	0.00246	13.801	0.07246	**50**
55	41.315	0.0242	575.929	0.00174	13.940	0.07174	**55**
60	57.946	0.0173	813.520	0.00123	14.039	0.07123	**60**
65	81.273	0.0123	1146.755	0.00087	14.110	0.07087	**65**
70	113.989	0.0088	1614.134	0.00062	14.160	0.07062	**70**
75	159.876	0.0063	2269.657	0.00044	14.196	0.07044	**75**
80	224.234	0.0045	3189.063	0.00031	14.222	0.07031	**80**
85	314.500	0.0032	4478.576	0.00022	14.240	0.07022	**85**
90	441.103	0.0023	6287.185	0.00016	14.253	0.07016	**90**
95	618.670	0.0016	8823.854	0.00011	14.263	0.07011	**95**
100	867.716	0.0012	12381.662	0.00008	14.269	0.07008	**100**

TABLE **3.8** 8 PER CENT COMPOUND INTEREST FACTORS

n	Single payment		Uniform payment series				n
	Compound-amount factor	Present-worth factor	Compound-amount factor	Sinking-fund factor	Present-worth factor	Capital-recovery factor	
	Given P to find S $(1+i)^n$	Given S to find P $\frac{1}{(1+i)^n}$	Given R to find S $\frac{(1+i)^n-1}{i}$	Given S to find R $\frac{i}{(1+i)^n-1}$	Given R to find P $\frac{(1+i)^n-1}{i(1+i)^n}$	Given P to find R $\frac{i(1+i)^n}{(1+i)^n-1}$	
1	1.080	0.9259	1.000	1.00000	0.926	1.08000	**1**
2	1.166	0.8573	2.080	0.48077	1.783	0.56077	**2**
3	1.260	0.7938	3.246	0.30803	2.577	0.38803	**3**
4	1.360	0.7350	4.506	0.22192	3.312	0.30192	**4**
5	1.469	0.6806	5.867	0.17046	3.993	0.25046	**5**
6	1.587	0.6302	7.336	0.13632	4.623	0.21632	**6**
7	1.714	0.5835	8.923	0.11207	5.206	0.19207	**7**
8	1.851	0.5403	10.637	0.09401	5.747	0.17401	**8**
9	1.999	0.5002	12.488	0.08008	6.247	0.16008	**9**
10	2.159	0.4632	14.487	0.06903	6.710	0.14903	**10**
11	2.332	0.4289	16.645	0.06008	7.139	0.14008	**11**
12	2.518	0.3971	18.977	0.05270	7.536	0.13270	**12**
13	2.720	0.3677	21.495	0.04652	7.904	0.12652	**13**
14	2.937	0.3405	24.215	0.04130	8.244	0.12130	**14**
15	3.172	0.3152	27.152	0.03683	8.559	0.11683	**15**
16	3.426	0.2919	30.324	0.03298	8.851	0.11298	**16**
17	3.700	0.2703	33.750	0.02963	9.122	0.10963	**17**
18	3.996	0.2502	37.450	0.02670	9.372	0.10670	**18**
19	4.316	0.2317	41.446	0.02413	9.604	0.10413	**19**
20	4.661	0.2145	45.762	0.02185	9.818	0.10185	**20**
21	5.034	0.1987	50.423	0.01983	10.017	0.09983	**21**
22	5.437	0.1839	55.457	0.01803	10.201	0.09803	**22**
23	5.871	0.1703	60.893	0.01642	10.371	0.09642	**23**
24	6.341	0.1577	66.765	0.01498	10.529	0.09498	**24**
25	6.848	0.1460	73.106	0.01368	10.675	0.09368	**25**
26	7.396	0.1352	79.954	0.01251	10.810	0.09251	**26**
27	7.988	0.1252	87.351	0.01145	10.935	0.09145	**27**
28	8.627	0.1159	95.339	0.01049	11.051	0.09049	**28**
29	9.317	0.1073	103.966	0.00962	11.158	0.08962	**29**
30	10.063	0.0994	113.283	0.00883	11.258	0.08883	**30**
31	10.868	0.0920	123.346	0.00811	11.350	0.08811	**31**
32	11.737	0.0852	134.214	0.00745	11.435	0.08745	**32**
33	12.676	0.0789	145.951	0.00685	11.514	0.08685	**33**
34	13.690	0.0730	158.627	0.00630	11.587	0.08630	**34**
35	14.785	0.0676	172.317	0.00580	11.655	0.08580	**35**
40	21.725	0.0460	259.057	0.00386	11.925	0.08386	**40**
45	31.920	0.0313	386.506	0.00259	12.108	0.08259	**45**
50	46.902	0.0213	573.770	0.00174	12.233	0.08174	**50**
55	68.914	0.0145	848.923	0.00118	12.319	0.08118	**55**
60	101.257	0.0099	1253.213	0.00080	12.377	0.08080	**60**
65	148.780	0.0067	1847.248	0.00054	12.416	0.08054	**65**
70	218.606	0.0046	2720.080	0.00037	12.443	0.08037	**70**
75	321.205	0.0031	4002.557	0.00025	12.461	0.08025	**75**
80	471.955	0.0021	5886.935	0.00017	12.474	0.08017	**80**
85	693.456	0.0014	8655.706	0.00012	12.482	0.08012	**85**
90	1018.915	0.0010	12723.939	0.00008	12.488	0.08008	**90**
95	1497.121	0.0007	18701.507	0.00005	12.492	0.08005	**95**
100	2199.761	0.0005	27484.516	0.00004	12.494	0.08004	**100**

TABLE **3.9** 10 PER CENT COMPOUND INTEREST FACTORS

	Single payment		Uniform payment series				
n	Compound-amount factor	Present-worth factor	Compound-amount factor	Sinking-fund factor	Present-worth factor	Capital-recovery factor	n
	Given P to find S $(1+i)^n$	Given S to find P $\frac{1}{(1+i)^n}$	Given R to find S $\frac{(1+i)^n-1}{i}$	Given S to find R $\frac{i}{(1+i)^n-1}$	Given R to find P $\frac{(1+i)^n-1}{i(1+i)^n}$	Given P to find R $\frac{i(1+i)^n}{(1+i)^n-1}$	
1	1.100	0.9091	1.000	1.00000	0.909	1.10000	**1**
2	1.210	0.8264	2.100	0.47619	1.736	0.57619	**2**
3	1.331	0.7513	3.310	0.30211	2.487	0.40211	**3**
4	1.464	0.6830	4.641	0.21547	3.170	0.31547	**4**
5	1.611	0.6209	6.105	0.16380	3.791	0.26380	**5**
6	1.772	0.5645	7.716	0.12961	4.355	0.22961	**6**
7	1.949	0.5132	9.487	0.10541	4.868	0.20541	**7**
8	2.144	0.4665	11.436	0.08744	5.335	0.18744	**8**
9	2.358	0.4241	13.579	0.07364	5.759	0.17364	**9**
10	2.594	0.3855	15.937	0.06275	6.144	0.16275	**10**
11	2.853	0.3505	18.531	0.05396	6.495	0.15396	**11**
12	3.138	0.3186	21.384	0.04676	6.814	0.14676	**12**
13	3.452	0.2897	24.523	0.04078	7.103	0.14078	**13**
14	3.797	0.2633	27.975	0.03575	7.367	0.13575	**14**
15	4.177	0.2394	31.772	0.03147	7.606	0.13147	**15**
16	4.595	0.2176	35.950	0.02782	7.824	0.12782	**16**
17	5.054	0.1978	40.545	0.02466	8.022	0.12466	**17**
18	5.560	0.1799	45.599	0.02193	8.201	0.12193	**18**
19	6.116	0.1635	51.159	0.01955	8.365	0.11955	**19**
20	6.727	0.1486	57.275	0.01746	8.514	0.11746	**20**
21	7.400	0.1351	64.002	0.01562	8.649	0.11562	**21**
22	8.140	0.1228	71.403	0.01401	8.772	0.11401	**22**
23	8.954	0.1117	79.543	0.01257	8.883	0.11257	**23**
24	9.850	0.1015	88.497	0.01130	8.985	0.11130	**24**
25	10.835	0.0923	98.347	0.01017	9.077	0.11017	**25**
26	11.918	0.0839	109.182	0.00916	9.161	0.10916	**26**
27	13.110	0.0763	121.100	0.00826	9.237	0.10826	**27**
28	14.421	0.0693	134.210	0.00745	9.307	0.10745	**28**
29	15.863	0.0630	148.631	0.00673	9.370	0.10673	**29**
30	17.449	0.0573	164.494	0.00608	9.427	0.10608	**30**
31	19.194	0.0521	181.943	0.00550	9.479	0.10550	**31**
32	21.114	0.0474	201.138	0.00497	9.526	0.10497	**32**
33	23.225	0.0431	222.252	0.00450	9.569	0.10450	**33**
34	25.548	0.0391	245.477	0.00407	9.609	0.10407	**34**
35	28.102	0.0356	271.024	0.00369	9.644	0.10369	**35**
40	45.259	0.0221	442.593	0.00226	9.779	0.10226	**40**
45	72.890	0.0137	718.905	0.00139	9.863	0.10139	**45**
50	117.391	0.0085	1163.909	0.00086	9.915	0.10086	**50**
55	189.059	0.0053	1880.591	0.00053	9.947	0.10053	**55**
60	304.482	0.0033	3034.816	0.00033	9.967	0.10033	**60**
65	490.371	0.0020	4893.707	0.00020	9.980	0.10020	**65**
70	789.747	0.0013	7887.470	0.00013	9.987	0.10013	**70**
75	1271.895	0.0008	12708.954	0.00008	9.992	0.10008	**75**
80	2048.400	0.0005	20474.002	0.00005	9.995	0.10005	**80**
85	3298.969	0.0003	32979.690	0.00003	9.997	0.10003	**85**
90	5313.023	0.0002	53120.226	0.00002	9.998	0.10002	**90**
95	8556.676	0.0001	85556.760	0.00001	9.999	0.10001	**95**
100	13780.612	0.0001	137796.123	0.00001	9.999	0.10001	**100**

TABLE 3.10 CAPITAL-RECOVERY FACTORS FOR INTEREST RATES FROM 6 PER CENT TO 50 PER CENT

Given P, to Find R

$$\frac{i(1+i)^n}{(1+i)^n - 1}$$

n	6%	8%	10%	12%	15%	20%	25%	30%	40%	50%	n
1	1.06000	1.08000	1.10000	1.12000	1.15000	1.20000	1.25000	1.30000	1.40000	1.50000	**1**
2	0.54544	0.56077	0.57619	0.59170	0.61512	0.65455	0.69444	0.73478	0.81667	0.90000	**2**
3	0.37411	0.38803	0.40211	0.41635	0.43798	0.47473	0.51230	0.55063	0.62936	0.71053	**3**
4	0.28859	0.30192	0.31547	0.32923	0.35027	0.38629	0.42344	0.46163	0.54077	0.62308	**4**
5	0.23740	0.25046	0.26380	0.27741	0.29832	0.33438	0.37184	0.41058	0.49136	0.57582	**5**
6	0.20336	0.21632	0.22961	0.24323	0.26424	0.30071	0.33882	0.37840	0.46126	0.54812	**6**
7	0.17914	0.19207	0.20541	0.21912	0.24036	0.27742	0.31634	0.35687	0.44192	0.53108	**7**
8	0.16104	0.17401	0.18744	0.20130	0.22285	0.26061	0.30040	0.34191	0.42804	0.52030	**8**
9	0.14702	0.16008	0.17364	0.18768	0.20957	0.24808	0.28876	0.33123	0.42034	0.51335	**9**
10	0.13587	0.14903	0.16275	0.17698	0.19925	0.23852	0.28007	0.32346	0.41432	0.50823	**10**
11	0.12679	0.14008	0.15396	0.16842	0.19107	0.23110	0.27349	0.31773	0.41013	0.50585	**11**
12	0.11928	0.13270	0.14676	0.16144	0.18448	0.22526	0.26845	0.31345	0.40718	0.50388	**12**
13	0.11296	0.12652	0.14078	0.15568	0.17911	0.22062	0.26454	0.31024	0.40510	0.50258	**13**
14	0.10758	0.12130	0.13575	0.15087	0.17469	0.21689	0.26150	0.30782	0.40363	0.50172	**14**
15	0.10296	0.11683	0.13147	0.14682	0.17102	0.21388	0.25912	0.30598	0.40259	0.50114	**15**
16	0.09895	0.11298	0.12782	0.14339	0.16795	0.21144	0.25724	0.30458	0.40185	0.50076	**16**
17	0.09544	0.10963	0.12466	0.14046	0.16537	0.20944	0.25576	0.30351	0.40132	0.50051	**17**
18	0.09236	0.10670	0.12193	0.13794	0.16319	0.20781	0.25459	0.30269	0.40094	0.50034	**18**
19	0.08962	0.10413	0.11955	0.13576	0.16134	0.20646	0.25366	0.30206	0.40067	0.50023	**19**
20	0.08718	0.10185	0.11746	0.13388	0.15976	0.20536	0.25292	0.30159	0.40048	0.50016	**20**
25	0.07823	0.09368	0.11017	0.12750	0.15470	0.20212	0.25095	0.30043	0.40009	0.50002	**25**
30	0.07265	0.08883	0.10608	0.12414	0.15230	0.20085	0.25031	0.30011	0.40002	0.50000	**30**
40	0.06646	0.08386	0.10226	0.12130	0.15056	0.20014	0.25003	0.30008	0.40001	0.50000	**40**
50	0.06344	0.08174	0.10086	0.12042	0.15014	0.20002	0.25000	0.30001	0.40000	0.50000	**50**
100	0.06018	0.08004	0.10001	0.12000	0.15000	0.20000	0.25000	0.30000	0.40000	0.50000	**100**
∞	0.06000	0.08000	0.10000	0.12000	0.15000	0.20000	0.25000	0.30000	0.40000	0.50000	**∞**

ous combinations of the three basic transformations just mentioned can be achieved, including such transformations as the conversion of an irregular series of payments into a uniform series of payments or a single payment at some particular time.

Compound interest tables giving in each case all six compound interest factors for a single interest rate are given in Tables 3.2 to 3.9, inclusive, for interest rates of 2 per cent, 3 per cent, 4 per cent, 5 per cent, 6 per cent, 7 per cent, 8 per cent, and 10 per cent, respectively. In addition, Table 3.10 gives capital-recovery factors only for various interest rates from 6 per cent to 50 per cent.

The mathematical derivation of the six compound interest factors may be found in books on the mathematics of finance.* The mathematics involved is not at all difficult and the actual use of the factors is extremely simple. The major attention in this discussion will be directed to the real meaning of each factor, how it can best be used, and to the relationship between the several factors. The mathematical expression for each factor may be found at the head of each column in Tables 3.2 to 3.9.

Tables 3.2 to 3.9 utilize standard symbols to indicate various elements utilized in compound interest calculations, but many persons prefer to think of these elements in terms of the words that describe them; this obviates the necessity

* Also in Grant, *Principles of Engineering Economy*, 3d ed.; Thuesen, *Engineering Economy*.

TABLE 3.11 PRESENT-WORTH FACTORS FOR INTEREST RATES FROM 6 TO 50 PER CENT*

$\frac{1}{(1+i)^n}$ Given S, to Find P

n	i 6%	8%	10%	12%	15%	20%	25%	30%	40%	50%	n
1	0.9434	0.9259	0.9091	0.8929	0.8696	0.8333	0.8000	0.7692	0.7143	0.6667	**1**
2	0.8900	0.8573	0.8264	0.7972	0.7561	0.6944	0.6400	0.5917	0.5102	0.4444	**2**
3	0.8396	0.7938	0.7513	0.7118	0.6575	0.5787	0.5120	0.4551	0.3636	0.2963	**3**
4	0.7921	0.7350	0.6830	0.6355	0.5718	0.4823	0.4096	0.3501	0.2603	0.1975	**4**
5	0.7473	0.6806	0.6209	0.5674	0.4972	0.4019	0.3277	0.2693	0.1859	0.1317	**5**
6	0.7050	0.6302	0.5645	0.5066	0.4323	0.3349	0.2621	0.2071	0.1328	0.0878	**6**
7	0.6651	0.5835	0.5132	0.4523	0.3759	0.2791	0.2097	0.1594	0.0949	0.0585	**7**
8	0.6274	0.5403	0.4665	0.4039	0.3269	0.2326	0.1678	0.1226	0.0678	0.0390	**8**
9	0.5919	0.5002	0.4241	0.3606	0.2843	0.1938	0.1342	0.0943	0.0484	0.0260	**9**
10	0.5584	0.4632	0.3855	0.3220	0.2472	0.1615	0.1074	0.0725	0.0346	0.0173	**10**
11	0.5268	0.4289	0.3505	0.2875	0.2149	0.1346	0.0859	0.0558	0.0247	0.0116	**11**
12	0.4970	0.3971	0.3186	0.2567	0.1869	0.1122	0.0687	0.0429	0.0176	0.0077	**12**
13	0.4688	0.3677	0.2897	0.2292	0.1625	0.0935	0.0550	0.0330	0.0126	0.0051	**13**
14	0.4423	0.3405	0.2633	0.2046	0.1413	0.0779	0.0440	0.0254	0.0090	0.0034	**14**
15	0.4173	0.3152	0.2394	0.1827	0.1229	0.0649	0.0352	0.0195	0.0064	0.0023	**15**
16	0.3936	0.2919	0.2176	0.1631	0.1069	0.0541	0.0281	0.0151	0.0046	0.0015	**16**
17	0.3714	0.2703	0.1978	0.1456	0.0929	0.0451	0.0225	0.0115	0.0033	0.0010	**17**
18	0.3503	0.2502	0.1799	0.1301	0.0808	0.0376	0.0180	0.0089	0.0023	0.0007	**18**
19	0.3305	0.2317	0.1635	0.1161	0.0703	0.0313	0.0144	0.0068	0.0017	0.0005	**19**
20	0.3118	0.2145	0.1486	0.1037	0.0611	0.0261	0.0115	0.0053	0.0012	0.0003	**20**
25	0.2330	0.1460	0.0923	0.0588	0.0304	0.0105	0.0038	0.0014	0.0002	....	**25**
30	0.1741	0.0994	0.0573	0.0334	0.0151	0.0042	0.0012	0.0004	.....	...	**30**
40	0.0972	0.0460	0.0221	0.0107	0.0037	0.0007	0.0001	....	.....	..	**40**
50	0.0543	0.0213	0.0085	0.0035	0.0009	0.0001	....	.....	....	. .	**50**
100	0.0029	0.0005	0.0001	. .	...	....	.....	.....	.....	....	**100**

* Used by permission of H. G. Thuesen.

for memorizing the meaning of abstract symbols. These symbols have the following meanings:

- i = the interest rate per interest period.
- n = the number of interest periods.
- P = a present sum of money.
- R = a single end-of-period payment in a series of n equal payments made at uniform intervals, the entire series being equivalent to P.
- S = a sum of money n periods hence, which is equivalent to either P or R, at interest rate i.

In most problems in engineering economy, it is satisfactory to consider that interest is compounded annually, in which case i is the interest rate per year, and n is the number of years. However, the tables may be used for any sort of compounding, such as semi-annually, quarterly, or monthly The rule is that i represents the interest rate per period, and n represents the number of periods. Thus with quarterly compounding and a nominal interest rate of 8 per cent over a 12-year period, i would be 2 per cent and n would be 48.

As was stated earlier, there is no need to memorize symbols or derivations when

using compound interest factors, but the following mnemonic symbols for the six factors will save time in identifying them and in using them in problems and examples:

$(\text{SPCAF})_i^n$ for Single-Payment Compound-Amount Factor
$(\text{SPPWF})_i^n$ for Single-Payment Present-Worth Factor
$(\text{USCAF})_i^n$ for Uniform-Series Compound-Amount Factor
$(\text{SFF})_i^n$ for Sinking-Fund Factor
$(\text{USPWF})_i^n$ for Uniform-Series Present-Worth Factor
$(\text{CRF})_i^n$ for Capital-Recovery Factor.

These mnemonic symbols are adapted from similar symbols developed by Clark Henderson of Stanford Research Institute.

3.1 SINGLE-PAYMENT COMPOUND-AMOUNT FACTOR

It will be noted from the mathematical expression for each factor as given at the head of each column of Tables 3.2 to 3.9 that $(1 + i)^n$ is the expression for the single-payment compound-amount factor, and also that the mathematical expression for each of the other factors contains this particular expression. Engineering handbooks and other non-financial handbooks often contain tables giving single-payment compound-amount factors but not the other five factors. In such cases, it is a simple matter to calculate any of the other five factors from the single-payment compound-amount factor for any desired value of i and n.

For that matter, if Tables 3.2 to 3.9 do not include the desired interest rate, and if no other table is available, it is a very simple matter with modern calculating machines to determine any desired single-payment compound-amount factor. For example, if $i = 1.5$ per cent and $n = 15$, the single-payment compound-amount factor will be $(1 + .015)^{15}$, which may also be indicated as $(1 + .015)\ (1 + .015)^2\ (1 + .015)^4\ (1 + .015)^8 = (1.015)\ (1.0302)\ (1.0614)\ (1.1265) = 1.2502$. Calculations of this type may be performed very rapidly on modern calculating machines and may also be handled easily by means of logarithms. However, in most cases values found by interpolation between factors in available tables should be accurate enough; there is no particular point in seeking accuracy in these factors that is greater than the accuracy of the data that are being used in the particular problem.

It is a very simple matter to use the single-payment compound-amount factor to find a future amount that is equivalent to a present amount, or in other words to find that future amount to which a present amount would increase at a certain compound interest rate. For example, $(\text{SPCAF})_{5\%}^{20}$ is given in Table 3.5 as 2.653, and the compound amount of \$1,000 after 20 years at 5 per cent compound interest is 1,000 (2.653) = \$2,653.

3.2 SINGLE-PAYMENT PRESENT-WORTH FACTOR

This factor, when multiplied by a future amount, will give the present worth of that future amount. It is obvious that the single-payment present-worth factor is the reciprocal of the single-payment compound-amount factor. As an example, the amount today (present worth) which will increase to \$1,000 in 20 years at 5 per cent compound interest is 1,000 $(\text{SPPWF})_{5\%}^{20}$ = 1,000 (0.3769) = \$376.90.

3.3 UNIFORM-SERIES COMPOUND-AMOUNT FACTOR

This factor, when multiplied by the amount of any payment of a uniform end-of-period series, will give the total amount at the end of the series of payments that is equivalent to the

series of payments. As always, it is understood that when there is a series of payments, each payment is made at the end of its period. (USCAF) $\frac{10}{5\%}$ is given in Table 3.5 as 12.578, and if \$1,000 is deposited in a fund at the end of each year for 10 years at 5 per cent compound interest, the amount in the fund at the end of 10 years will be 1,000 (12.578) = \$12,578.

3.4 SINKING-FUND FACTOR

This factor is used when it is desired to determine the magnitude of each of a series of equal end-of-period payments that will increase to some desired amount at the end of the total period of time at the stated compound interest rate. It is obviously the reciprocal of the uniform-series compound-amount factor. (SFF) $\frac{20}{5\%}$ is given in Table 3.5 as 0.03024. If it is desired to build up a fund of \$10,000 at the end of 20 years, making equal end-of-year sinking-fund payments each year, and with compound interest at 5 per cent, each of these sinking-fund payments will be 10,000 (0.03024) = \$302.40.

3.5 UNIFORM-SERIES PRESENT-WORTH FACTOR

This factor, when multiplied by one of a series of equal end-of-period payments, gives the present worth at the beginning of the first period. (USPWF) $\frac{10}{5\%}$ is given in Table 3.5 as 7.722. Thus the present worth of a series of 10 end-of-year payments of \$1,000, each with 5 per cent compound interest, is 1,000 (7.722) = \$7,722. There are always several ways to express these transformations. For example, at 5 per cent compound interest, \$7,722 now is equivalent to \$1,000 at the end of each of the next 10 years. Also at 5 per cent compound interest, we could afford to make a single payment of \$7,722 now to avoid having to make payments of \$1,000 at the end of each year for the next 10 years.

3.6 CAPITAL-RECOVERY FACTOR

In engineering economy, this is by far the most important of the six compound interest factors. By means of this factor one can distribute a present amount uniformly over a future interval of time by means of uniform end-of-period amounts. This concept may be expressed in a great many ways, one of them being the repayment of a loan through uniform annual end-of-year payments, such as the loan repayment of plan 3 of Table 3.1. (CRF) $\frac{5}{5\%}$ is given in Table 3.5 as 0.23097. Thus the amount that must be paid back at the end of each year for 5 years in order to repay with 5 per cent interest a loan of \$10,000 is 10,000 (0.23097) = \$2,309.70. This, of course, was proved to be the correct amount by the calculations of plan 3 of Table 3.1.

It is obvious that the capital-recovery factor is the reciprocal of the uniform-series present-worth factor. Thus the six compound interest factors form three pairs in which the factors in each pair are reciprocals.

There is an extremely important relationship between the capital-recovery factor and the sinking-fund factor. It is not obvious from the mathematical expressions at the top of the columns for the capital-recovery factor and the sinking-fund factor, but these expressions may readily be rearranged so as to prove that the capital-recovery factor is always equal to the sinking-fund factor plus the interest rate. An examination of the values of these two factors in Tables 3.2 to 3.9 will show that this is true for every value of n in all these tables.

It was stated earlier that engineering handbooks and other non-financial handbooks often contain tables for single-payment compound-amount factors but not for the other five compound interest factors. Few of these handbooks contain

tables for capital-recovery factors, but some of them do contain tables for sinking-fund factors, from which a capital-recovery factor may easily be derived by simply adding the interest rate to the appropriate sinking-fund factor.

The reason why the capital-recovery factor is equal to the sinking-fund factor plus the interest rate may easily be explained. It will be noted from plans 1 and 3 of Table 3.1 that a loan of $10,000 may be repaid in 5 years with interest at 5 per cent by paying $500 interest at the end of each year plus $10,000 at the end of the 5-year period, or by paying $2,309.75 (partly interest and partly principal) at the end of each year of the 5-year period. If the contract calls for payments according to plan 1 but the borrower desires to pay off the principal of the loan in equal annual installments, he may make separate payments of $1,809.75 at the end of each year for 5 years, and thus provide a sinking fund of $10,000 to pay off the principal of the loan when it becomes due. Thus the interest payments of $500 per year plus the sinking-fund payments of $1,809.75 per year are equal to the capital-recovery payments of $2,309.75 per year, and the capital-recovery factor is therefore equal to the sinking-fund factor plus the interest rate.

3.7 TYPICAL COMPOUND INTEREST PROBLEMS

Many problems involving compound interest may be expressed in several different ways, or perhaps it would be better to say that many problems that seem to be quite different are really the same problem as far as the compound interest solution is concerned. In the form in which it is first stated, the following problem is probably the most frequent of all compound interest problems in engineering economy, and it will be noted that all of the eight different ways in which the problem is stated lead to the same solution:*

1. What is the equivalent uniform annual capital-recovery cost at 5 per cent interest of a machine having a first cost of $10,000, zero salvage value, and a life of 5 years?
2. If $10,000 is invested in a machine with an estimated life of 5 years and zero salvage value, what is the equivalent uniform annual sum of interest and depreciation, with interest at 5 per cent? (This is really plan 3, Table 3.1, with the investor replacing the lender and anticipating that he will get his money back, plus 5 per cent interest, through the operation of the machine.)
3. What annual saving for 5 years must be anticipated in order to justify a present expenditure of $10,000, if money is worth 5 per cent in this particular situation?
4. What 5-year annuity can be purchased for $10,000, with interest at 5 per cent?
5. If $10,000 is deposited now, with interest at 5 per cent what uniform amount could be withdrawn at the end of each year for 5 years, with nothing to be left in the fund at the end of the 5th year?
6. If $10,000 is loaned for 5 years at 5 per cent interest, what equal annual end-of-year payment would just repay the loan by the end of the 5 years? (This, of course, is plan 3, Table 3.1.)
7. What is the uniform annual end-of-year payment for 5 years, with 5 per cent interest, for which the present worth is $10,000?
8. With interest at 5 per cent, what uniform end-of-year payment for 5 years is equivalent to $10,000 now?

From the viewpoint of the mathematical solution, these are merely eight statements of the same problem, which may be solved by multiplying $10,000 by $(\text{CRF})_{5\%}^{5}$. Thus, in each of these eight cases, the answer is 10,000 (0.23097) = $2,309.70. (In many cases, there will

* This problem is adapted from Example 16, page 59, of Grant, *Principles of Engineering Economy*, 3d ed. There are 23 of these worked-out examples, most of them stated in several different ways, which illustrate many different types of compound interest problems.

be slight differences in solutions that are really identical, because of a certain rounding off of factors. Thus $(\mathrm{CRF})_{5\%}^{5}$ may be stated as 0.23097, 0.230975, or 0.2309748, depending upon the number of significant figures to which the factor is carried in the table used.)

It was stated earlier that compound interest factors are used to make money amounts comparable where such amounts are not comparable in their original form. A single payment may be transformed into an equivalent series of payments, or vice versa. It is also possible by using several factors successively to transform any sort of irregular series of payments into a single payment at any specified time, or into any desired uniform series of payments.

Suppose, for example, it is desired to convert the following very irregular series of payments into an equivalent uniform annual series of payments at 5 per cent interest over the stated 30-year period:

$1,000 now and at 10 and 20 years from now
$200 per year for the first 8 years
$300 per year for the years 9 to 16, inclusive
$200 per year for the years 17 to 23, inclusive
$400 per year for the years 24 to 30, inclusive

There are many ways to solve this problem, which is very simple in theory even if tedious in practice. In most cases where an irregular series is to be converted into a uniform series, it is best first to convert the irregular series into a single payment at either the beginning of the period (present worth) or at the end of the period (compound amount). In almost all cases, it is better to use the present-worth approach because the values to be handled are so much more manageable. This problem will now be solved by finding the present worth of the entire series of payments by means of two different methods.

By the first method, the present worth is

$$1{,}000 + 1{,}000(\mathrm{SPPWF})_{5\%}^{10} + 1{,}000(\mathrm{SPPWF})_{5\%}^{20} + 200(\mathrm{USPWF})_{5\%}^{8} + 300(\mathrm{USPWF})_{5\%}^{8}(\mathrm{SPPWF})_{5\%}^{8} + 200(\mathrm{USPWF})_{5\%}^{7}(\mathrm{SPPWF})_{5\%}^{16} + 400(\mathrm{USPWF})_{5\%}^{7}(\mathrm{SPPWF})_{5\%}^{23} =$$

$$1{,}000 + 1{,}000(0.6139) + 1{,}000(0.3769) + 200(6.463) + 300(6.463)(0.6768) + 200(5.786)(0.4581) + 400(5.786)(0.3256) =$$

$$1{,}000.00 + 613.90 + 376.90 + 1{,}292.60 + 1{,}312.20 + 530.10 + 753.60 = \$5{,}879.30.$$

When using the second method, it may be noted that there is a uniform payment of $200 per year for the entire 30-year period. Thus the calculations for finding the present worth of the entire series may be stated somewhat more simply as

$$1{,}000 + 1{,}000(\mathrm{SPPWF})_{5\%}^{10} + 1{,}000(\mathrm{SPPWF})_{5\%}^{20} + 200(\mathrm{USPWF})_{5\%}^{30} + 100(\mathrm{USPWF})_{5\%}^{8}(\mathrm{SPPWF})_{5\%}^{8} + 200(\mathrm{USPWF})_{5\%}^{7}(\mathrm{SPPWF})_{5\%}^{23} =$$

$$1{,}000(1.0 + 0.6139 + 0.3769) + 200(15.372) + 100(6.463)(0.6768) + 200(5.786)(0.3256) = 1{,}990.80 + 3{,}074.40 + 437.40 + 376.80 = \$5{,}879.40.$$

The desired equivalent uniform annual cost for the irregular series is, of course, $5{,}879.40(\mathrm{CRF})_{5\%}^{30} = 5{,}879.40(0.06505) = \$382.50$.

Either of these two methods is perfectly straightforward and undoubtedly such methods are the safest to use. However, in this case there is another and considerably simpler method. An inspection of the data shows that the equivalent uniform annual cost for the three $1,000 payments is simply $1{,}000(\mathrm{CRF})_{5\%}^{10} = 1{,}000(0.12950) = \$129.50$. (This is true for each of the three $1,000 payments and therefore for the entire 30-year period.) Also there is no need to find the present worth of the $200

per year payment which extends over the entire period; it is already in the form finally desired. The present worth of the remaining irregular payments will be, as before, 100(6.463)(0.6768) + 200(5.786)(0.3256) = \$814.20, and the equivalent uniform annual cost for this part of the problem will be 814.20(0.06505) = \$53.00. The total equivalent uniform annual cost will be 129.50 + 200.00 + 53.00 = \$382.50.

4. ANNUAL COST

Most engineering economy studies involve both initial investments and subsequent annual disbursements. The typical situation is for alternative A to have a higher first cost but lower annual disbursements or longer life than alternative B. In determining whether the advantages of A due to lower annual disbursements or longer life are sufficient to justify the higher first cost, it is necessary to make calculations that will produce comparable figures for the various alternatives. The three ways most often used to do this are:

1. Annual cost.
2. Present worth.
3. Rate of return on additional investment.

The annual-cost method seems to be the most frequently used method, and its characteristics certainly are well adapted for use in the manufacturing industries for most kinds of engineering economy studies. Manufacturing executives have long been familiar with the distribution of an investment over the life of an asset through depreciation charges, and, as will be pointed out a little later in this article, it is even satisfactory in many cases to use a so-called "straight-line depreciation and average interest" method that avoids the use of compound interest calculations. However, it should be remembered that comparisons made by means of compound interest calculations are the only ones that are mathematically accurate, and, in addition, compound interest calculations are always at least as easy to use as the approximate methods so often recommended by persons who do not care to take the trouble to make the simple investigation that is required in order to understand the basis for compound interest calculations.

4.1 EXACT VS. APPROXIMATE METHODS

Plans 3 and 2 of Table 3.1 may be used to illustrate the exact and approximate methods of calculating the cost of recovering an investment of \$10,000 in 5 years, with 5 per cent interest. As was pointed out earlier in this section, these two plans are equivalent to each other and produce exact results from the viewpoint of interest each year on the investment during that year. In addition, plan 3 may be used without change to determine the uniform annual cost of capital recovery, as the year-end payments are merely the initial investment multiplied by the capital-recovery factor $(\mathrm{CRF})_{5\%}^{5}$. Thus plan 3 of Table 3.1 illustrates the exact method of determining the annual cost of recovering an investment for use in the annual-cost method.

It will be noted that the year-end payments in plan 2 of Table 3.1 are really made up of two parts. The first part is the uniform reduction in the principal, and these uniform amounts of \$2,000 at the end of each year obviously correspond to the straight-line depreciation charges for an asset with an initial investment of \$10,000 and a life of 5 years, with zero salvage value. The second part of the year-end payments is not usable directly in annual-cost calculations because what is required is a uniform annual cost. In the approximate method of calculating annual costs for capital recovery (generally called the method of "straight-line depreciation and average interest"), the interest part of this annual cost is determined by simply taking the straight average of the interest that would be due each year on the unrepaid loan (or investment). It is obvious that the "average interest" in plan 2 of Table 3.1 is

$$\frac{500 + 100}{2} = \$300$$

It can readily be shown that for any life n, interest rate i, and investment P, the average interest as found by the approximate method will be

$$\left(\frac{Pi}{2}\right)\left(\frac{n+1}{n}\right)$$

Using this formula for plan 2 of Table 3.1, we find that the "average interest" is

$$\left(\frac{10{,}000 \times 0.05}{2}\right)\left(\frac{5+1}{5}\right) = \$300$$

as found above by merely averaging the several interest payments shown in plan 2.

Table 3.12 gives average interest factors for use in determining the average annual interest when using the approximate (straight-line depreciation and average interest) method. The average interest for any given situation is determined by multiplying the first cost by the factor corresponding to the stated life and interest rate. For the situation of plan 2 of Table 3.1, the first cost is \$10,000, the life is 5 years, and the interest rate is 5 per cent. From Table 3.12, the average interest factor is 0.0300, and the average interest is 10,000 (0.0300) = \$300 per year.

Payments of \$300 at the end of each year for 5 years total \$1,500, which is exactly the same total as for the series of interest payments shown in plan 2 of Table 3.1. However, \$300 per year for 5 years is obviously not equivalent to the decreasing series of \$500, \$400, \$300, \$200, and \$100 of plan 2 of Table 3.1; the decreasing series is obviously better for the recipient, since \$200 is received 4 years sooner and \$100 is received 2 years sooner.

It is a simple matter to determine the uniform annual series that is actually equivalent to the decreasing series of interest payments of plan 2 of Table 3.1, by finding the present worth of the series at the beginning of the series and then multiplying this by the capital-recovery factor. This calculation is as follows:

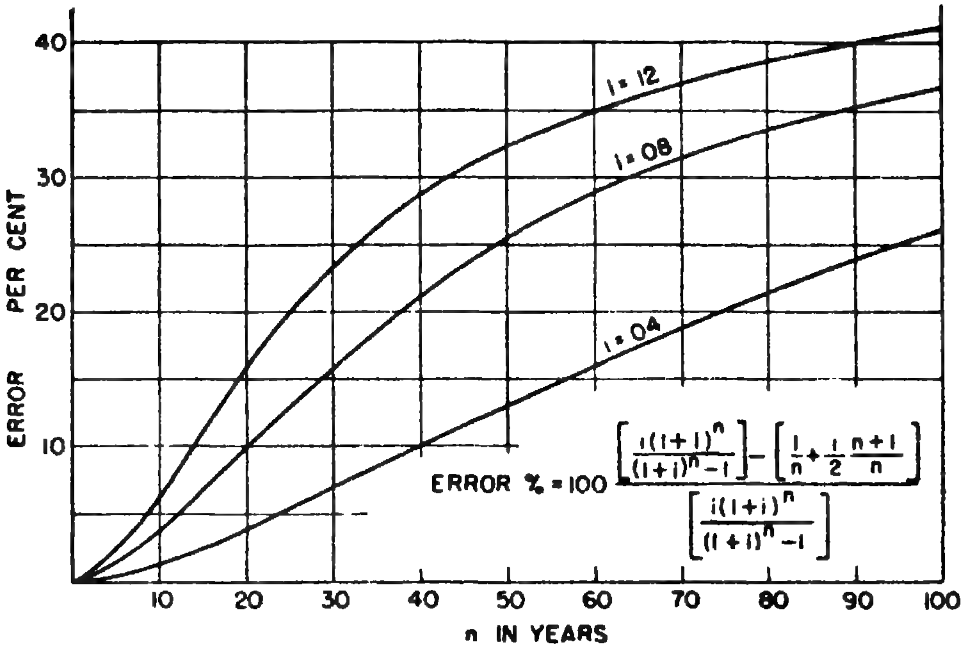
[500(0.9524) + 400(0.9070) + 300 (0.8638) + 200(0.8227) + 100(0.7835)] (0.23097) = (476.20 + 362.80 + 259.14 + 164.54 + 78.35)(0.23097) = (1,341.03)(0.23097) = \$309.74.

It will be noted that this accurate figure for the equivalent uniform annual cost of the decreasing interest series when added to the depreciation figure of \$2,000 per year gives the same total for the equivalent uniform cost of capital recovery (depreciation plus interest) determined in plan 3 of Table 3.1.

A simple average of a series of decreasing interest charges is always less

TABLE 3.12 AVERAGE INTEREST FACTORS FOR USE IN APPROXIMATE METHOD OF DETERMINING ANNUAL COST OF CAPITAL RECOVERY

n	i							
	2%	3%	4%	5%	6%	7%	8%	10%
1	0.0200	0.0300	0.0400	0.0500	0.0600	0.0700	0.0800	0.1000
2	0.0150	0.0225	0.0300	0.0375	0.0450	0.0525	0.0600	0.0750
3	0.0133	0.0200	0.0267	0.0333	0.0400	0.0467	0.0533	0.0667
4	0.0125	0.0188	0.0250	0.0313	0.0375	0.0438	0.0500	0.0625
5	0.0120	0.0180	0.0240	0.0300	0.0360	0.0420	0.0480	0.0600
6	0.0117	0.0175	0.0233	0.0292	0.0350	0.0408	0.0467	0.0583
7	0.0114	0.0171	0.0229	0.0286	0.0343	0.0400	0.0457	0.0571
8	0.0113	0.0169	0.0225	0.0281	0.0338	0.0394	0.0450	0.0563
9	0.0111	0.0167	0.0222	0.0278	0.0333	0.0389	0.0444	0.0556
10	0.0110	0.0165	0.0220	0.0275	0.0330	0.0385	0.0440	0.0550



Thuesen, *Engineering Economy*, p 93.

FIG. **3.1** INACCURACY OF APPROXIMATE CAPITAL-RECOVERY FACTORS.

than the accurate equivalent uniform annual value of the series. Figure 3.1 shows that for short lives and low interest rates the difference between the capital recovery costs as found by means of the exact and the approximate methods is negligible, but that the inaccuracy increases materially for long lives and high interest rates. For example, the inaccuracy in the two methods for the conditions of Table 3 1 has been found to be \$2,309 75 − \$2,300 00 = \$9.75, or only about 0.4 per cent. The curves in Fig. 3.1 show that for lives of 10 years or less and for interest rates of 10 per cent or less the inaccuracy of the approximate method will be 5 per cent or less. In view of the inherent inaccuracy of many of the data used in engineering economy studies, the approximate method is probably accurate enough for most studies of manufacturing equipment, but not for buildings or other assets with prospective lives considerably longer than 10 years.

Since it is the differences between alternatives that govern decisions in engineering economy studies, inaccuracies of similar magnitude in the calculation of annual costs for various alternatives may result in inaccuracies in the differences that are even less significant than the inaccuracies in the annual costs themselves. Because of the way the inaccuracies of the approximate method affect total annual costs, a good rule to follow is that the approximate method should not be used when:

1. Study-period lives are longer than 10 years.
2. Study-period lives are markedly different for the several alternatives.
3. The relative importance of initial investments and annual disbursements is markedly different for the several alternatives.

4.2 EXAMPLE 1, ALTERNATIVES WITH EQUAL LIVES AND ZERO SALVAGE VALUES

Machine A has a first cost of \$7,000 and estimated annual cash disbursements during life of \$2,500. Machine B has a first cost of \$10,000 and estimated annual cash disbursements during life of \$2,000. Each machine is estimated to have a life of 10 years, with zero salvage value at the end of life

Minimum attractive rate of return is considered to be 6 per cent for either investment, when due consideration is given to the risks involved.

Annual costs for the two machines by the accurate compound interest method are:

Machine A

Cap. rec. cost 7,000(0.13587)	= $ 951
Annual disbursements	= 2,500
Total annual cost	= $3,451

Machine B

Cap. rec. cost 10,000(0.13587)	= $1,359
Annual disbursements	= 2,000
Total annual cost	= $3,359

Annual costs for the two machines by the approximate method are:

Machine A

Straight-line deprec. $\frac{7,000}{10}$	= $ 700
Average interest 7,000(0.0330)	= 231
Annual disbursements	= 2,500
Total annual cost	= $3,431

Machine B

Straight-line deprec. $\frac{10,000}{10}$	= $1,000
Average interest 10,000(0.0330)	= 330
Annual disbursements	= 2,000
Total annual cost	= $3,330

It will be noted that when annual costs are calculated by the accurate compound interest method, machine B appears to have an advantage over machine A of $92 per year, whereas when the approximate method is used, the advantage appears to be $101 per year. This inaccuracy of $9 in the apparent advantage of B over A is much less than the inaccuracies in total annual cost of $20 and $29 for A and B respectively when the approximate method is used to determine such cost. The reason for this is obviously the fact that the inaccuracies are in the same direction for both machines. The inaccuracies of the approximate method are, of course, in the investment part of the annual cost only, and in this case (because of equal lives and zero salvage values) the inaccuracies vary directly with the amount of the investment in each machine.

4.3 EXAMPLE 2, ALTERNATIVES WITH POSITIVE SALVAGE VALUES

When it is anticipated that there will be a positive salvage value at the end of the life of an asset, the most satisfactory way to determine the annual cost of capital recovery is to separate the investment into two parts, one being the part that depreciates to zero, and the other being the salvage value itself. It is obvious that the only annual capital cost for the salvage-value portion of the first cost is the amount of the salvage value multiplied by the interest rate.

Machine C has a first cost of $8,000, with anticipated salvage value of $2,000 at the end of the estimated life of 10 years, and prospective cash disbursements during life of $1,500 per year. Machine D has a first cost of $12,000, with anticipated salvage value of $4,000 at the end of the estimated life of 10 years, and prospective cash disbursements during life of $1,000 per year. Minimum attractive rate of return is 6 per cent.

Annual costs for the two machines by the accurate compound interest method are:

Machine C

Cap. rec. cost 6,000(0.13587)	= $ 815
Int on salv. val. 2,000(0.06)	= 120
Annual disbursements	= 1,500
Total annual cost	= $2,435

Machine D

Cap. rec. cost 8,000(0.13587)	= $1,087
Int. on salv. val. 4,000(0.06)	= 240
Annual disbursements	= 1,000
Total annual cost	= $2,327

Annual costs for the two machines by the approximate method are:

Machine C

Straight-line deprec. $\frac{6,000}{10}$	=	\$ 600
Average interest 6,000(0.0330)	=	198
Int. on salv. val. 2,000(0.06)	=	120
Annual disbursements	=	1,500
Total annual cost	=	\$2,418

Machine D

Straight-line deprec. $\frac{8,000}{10}$	=	\$ 800
Average interest 8,000(0.0330)	=	264
Int. on salv. val. 4,000(0.06)	=	240
Annual disbursements	=	1,000
Total annual cost	=	\$2,304

The apparent advantage of machine D over machine C is \$108 per year by the accurate method and \$114 per year by the approximate method. The inaccuracies in total annual cost are \$17 and \$23 respectively for C and D when the approximate method is used to determine such cost.

4.4 EXAMPLE 3, ALTERNATIVES WITH DIFFERENT LIVES

Structure E has a first cost of \$6,000, with anticipated zero salvage value at the end of the estimated life of 10 years, and prospective cash disbursements during life of \$1,100 per year. Structure F has a first cost of \$20,000, with anticipated salvage value of \$5,000 at the end of the estimated life of 25 years, and prospective cash disbursements during life of \$600 per year. Minimum attractive rate of return is 5 per cent.

Annual costs for the two structures by the accurate compound interest method are:

Structure E

Cap. rec. cost 6,000(0.12950)	=	\$ 777
Int. on salv. val.		....
Annual disbursements	=	1,100
Total annual cost	=	\$1,877

Structure F

Cap. rec. cost 15,000(0.07095)	=	\$1,064
Int. on salv. val. 5,000(0.05)	=	250
Annual disbursements	=	600
Total annual cost	=	\$1,914

Annual costs for the two structures by the approximate method are:

Structure E

Straight-line deprec. $\frac{6,000}{10}$	=	\$ 600
Average interest 6,000(0.0275)	=	165
Int. on salv. val.		..
Annual disbursements	=	1,100
Total annual cost	=	\$1,865

Structure F

Straight-line deprec. $\frac{15,000}{25}$	=	\$ 600
Average interest 15,000(0.0260)	=	390
Int. on salv. val. 5,000(0.05)	=	250
Annual disbursements	=	600
Total annual cost	=	\$1,840

Because of the differences in the prospective lives of the two alternatives, and also the greater relative importance of the investment portion in F, the inaccuracy due to using the approximate method is much greater for F than for E (\$74 for F and \$12 for E). Because of this, the apparent advantage for E of \$37 per year indicated by the accurate method is changed to an apparent advantage for F of \$25 per year when the approximate method is used.

A study of the results of this example will demonstrate two important points that should be considered when making engineering economy studies. The first applies to all such studies and the second to the choice between the accurate and approximate methods when determining the equivalent uniform annual costs of various alternatives that are under consideration.

When the computed differences between alternatives are small, the final decision must usually be based primarily upon differences that were not reduced to money terms in the study itself, and that often cannot be so reduced. It is no longer safe to base decisions in these matters completely on a manager's judgment, no matter how able and experienced the manager may be, but judgment factors will always play an important part in these decisions, especially when the computed differences in the tangible factors are small.

In this connection, it is well to note the advantage of using a study method that gives both the differences between alternatives and also the magnitudes from which the differences were obtained, as compared with using formulas that give merely differences between alternatives. True, it is the differences between alternatives that one is interested in, but often one needs to know more than the differences before one can make a proper decision. For example, consider the use of a formula that merely indicates that A is better than B by $500 per year. If the annual costs of A and B are $1,000 and $1,500 respectively, this difference is certainly significant, whereas if the annual costs are $50,000 and $50,500 respectively, the difference would ordinarily be meaningless. This particular disadvantage of using typical engineering economy formulas is not generally recognized.

The differences between the results obtained in example 3 when using the accurate and approximate methods demonstrate the undesirability of the approximate method where the several alternatives have considerable differences in prospective lives or in the relative importance of the investment portion of the annual cost. The accurate compound interest method is so simple in both theory and practice that it can be efficiently used with little effort.

4.5 SIGNIFICANCE OF DIFFERENCES IN LIVES OF ALTERNATIVES

In example 3, the solution by means of the accurate method indicated annual costs of $1,877 and $1,914 respectively for E and F. However, these costs were for a life of 10 years for E and of 25 years for F. It should be noted that the use of a life of 25 years for F implied not only an estimate that F could be used for that period, but, what is often even more significant, that the service for which E and F are both being considered would be required for at least 25 years. It is obvious that anything (including a discontinuance of the need for the service) that would reduce the useful life of F below 25 years would tend to increase the annual cost if alternative F were selected. All other things being equal, one should favor the alternative with the shorter life, because of the risk that the need for the service may not extend beyond that period. In this case, even the tangible results indicate a slight advantage for the alternative with the shorter life, and if there were no other important intangible factors favoring F, it is probable that E would be selected.

The fact that an alternative having a life longer than that of some other possible alternative is even being considered is proof that the chances are considered good that the service will be required during the longer period. Risks of this sort should be given consideration through the value placed on the minimum attractive rate of return used in the study. Business profits cannot be secured without risk, but engineering economy studies should be made in ways that will as far as possible measure the risks that are present in the particular situation being studied.

The fact that the calculations of example 3 were made by merely calculating the prospective annual costs of E for 10 years and of F for 25 years not only implied that there was a reasonably good chance that the service would be required for 25 years (or else that F could be used for some similar purpose for the full 25-year period) but also that if E were selected, the annual cost for its successor would also be $1,877 per year. If there were reason to believe that the successor to E would have a different annual cost experience after it was installed, the study should take that into consideration through specific calculations. However, it should be clearly understood that in all such studies the decision that is made is merely a decision on what will be done now.

5. PRESENT WORTH

The previous article explained how alternatives may be made comparable through the annual-cost method,

in which the first cost of an asset is distributed over the prospective life of the asset and added to annual cash disbursements. This article will explain a procedure that is practically the reverse of the annual-cost method, and that is called the present-worth method. This method also makes alternatives comparable, but does so by using compound interest calculations to determine a single amount that is equivalent to the series of annual cash disbursements, and that is added to the first cost of the asset, so as to give a single amount that is equivalent to both the first cost and the annual cash disbursements.

5.1 EXAMPLE 4, ALTERNATIVES WITH EQUAL LIVES AND ZERO SALVAGE VALUES

In this example, the data of example 1 will be used to compare machines A and B by means of the present-worth method. The calculations are shown at the bottom of the page.

These figures really mean that if $25,400 were placed in a fund bearing interest at 6 per cent, all payments required for the life of machine A could be made out of the fund, with nothing remaining in the fund at the end of 10 years. The $18,400 remaining in the fund after the initial payment of $7,000 for the machine would be just sufficient to make the 10 annual cash disbursements of $2,500 at the end of each year for the 10-year period. In a similar way, $24,720 placed in a 6 per cent fund now would purchase machine B and also take care of the 10 annual cash disbursements of $2,000 at the end of each year for 10 years.

It is obvious that the present-worth figure of $25,400 and the annual-cost figure of $3,451 for machine A are equivalent to each other at 6 per cent compound interest for a 10-year period. $25,400(0.13587) = $3,451 and $3,451 (7.360) = $25,400. The same is true for machine B and for all other alternatives for which compound interest calculations are made for both annual costs and present worths.

The present-worth calculations of this example indicate that B is better than A to the extent that the present deposit at 6 per cent required to take care of all disbursements for 10 years, including the purchase of the machines, is $680 less for B than for A.

5.2 EXAMPLE 5, ALTERNATIVES WITH POSITIVE SALVAGE VALUES

It should be obvious that from the standpoint of comparability, the prospect that an asset will have a positive salvage value at the end of its life will reduce the present worth of the amounts required to own and operate the asset by the present worth of the salvage value as of the time the asset is purchased. Using the data of example 2, the present worths for machines C and D are as shown on p. 130.

The present-worth calculations of this example indicate that D is better than C to the extent that the present deposit at 6 per cent required to take care of all disbursements for 10 years, including the purchase of the machines, is $796 less

Machine A

First cost	= $ 7,000
PW of annual disbursements 2,500(7.360)	= 18,400
Total PW of all disbursements for 10 years	= $25,400

Machine B

First cost	= $10,000
PW of annual disbursements 2,000(7.360)	= 14,720
Total PW of all disbursements for 10 years	= $24,720

Machine C

First cost	= $ 8,000
PW of annual disbursements 1,500(7.360)	= 11,040
Total PW of all disbursements for 10 years	= $19,040
Less: PW of salvage value 2,000(0.5584)	= 1,117
PW of net disbursements for 10 years	= $17,923

Machine D

First cost	= $12,000
PW of annual disbursements 1,000(7.360)	= 7,360
Total PW of all disbursements for 10 years	= $19,360
Less: PW of salvage value 4,000(0.5584)	= 2,234
PW of net disbursements for 10 years	= $17,126

for D than for C. $796(0.13587) = $108. Thus the results of examples 2 and 5 are equivalent at 6 per cent compound interest.

5.3 EXAMPLE 6, ALTERNATIVES WITH DIFFERENT LIVES

When comparing alternatives by means of the present-worth method, it is necessary that the study period be the same for each alternative. For lives of 10 years and 25 years, as in example 3, it is necessary that the study period be the least common multiple of these lives (50 years), and also that definite assumptions be made as to the first cost of each renewal of an asset and as to the annual disbursements for the entire study period. It is usual to assume that the first cost of all renewals and all annual disbursements will remain the same as at the beginning of the study period. Under these conditions, and using the data of example 3, the present worths for 50 years of structures E and F are as shown below

The present-worth calculations of this example indicate that E is better than F to the extent that the present deposit at 5 per cent required to take care of all disbursements for 50 years, including first cost of present and replacement structures, is $682 less for E than for F. As $682(0.05478) = $37, the results of examples 3 and 6 are equivalent at 5 per cent compound interest.

Structure E

First cost	= $ 6,000
PW of first renewal 6,000(0.6139)	= 3,683
PW of second renewal 6,000(0.3769)	= 2,261
PW of third renewal 6,000(0.2314)	= 1,388
PW of fourth renewal 6,000(0.1420)	= 852
PW of annual disbursements for 50 years 1,100(18.256)	= 20,082
PW of all disbursements for 50 years	= $34,266

Structure F

First cost	= $20,000
PW of first renewal 15,000(0.2953)	= 4,430
PW of annual disbursements for 50 years 600(18.256)	= 10,954
PW of all disbursements for 50 years	= $35,384
Less: PW of final salvage value 5,000(0.0872)	= 436
PW of net disbursements for 50 years	= $34,948

5.4 ANNUAL COST VS. PRESENT WORTH

Examples 1 to 6 illustrate a type of problem found very frequently in the manufacturing industries, and it is obvious from an examination of the solutions that the annual-cost approach is better than the present-worth approach for this type of problem. Neither of the two methods is inherently superior to the other, but it would seem that the annual-cost method is generally better where each alternative requires a single capital investment plus annual disbursements that are estimated to be uniform over the study period, whereas the present-worth method is generally better where there are several capital investments during the study period and annual disbursements may be expected to vary considerably during the study period.

Selection of the method to be used in any given case should depend upon the existing conditions, but the annual-cost method has characteristics that make it the better method for most engineering economy studies in the manufacturing industries. One great advantage is that manufacturing executives are more familiar with the procedures used in the annual-cost method and are better able to interpret the results. A possible objection to the present-worth method is that the average person does not seem to realize how great a difference in the mathematical figures may result from what seems to be a small change in the interest rate.

5.5 PRESENT-WORTH CONCEPT ESSENTIAL FOR MANY PURPOSES

Although the annual-cost approach is better than the present-worth approach in many engineering economy studies, it must be remembered that, in the final analysis, what one is justified in paying for or investing in a business property is the present worth of the prospective receipts from the property, the compound interest rate being the minimum attractive rate of return. There are doubtless many cases where present-worth calculations would be used if it were realized that they could be expected to give the best available information under the existing conditions.

5.6 EXAMPLE 7, VALUATION OF A BOND

A corporate bond (or any other interest-bearing obligation) may be valued by means of the present-worth method. For example, it is desired to determine how much one could afford to pay for a 3 per cent, $1,000 corporate bond due 20 years hence, if the minimum attractive rate of return on this investment is considered to be 4 per cent. Interest payments of $15 are made every 6 months, and the valuation will be made on the basis of semi-annual compounding. In other words, in valuing the bond, $i = 2$ per cent, and $n = 40$ periods. On this basis, the valuation to be placed on the bond will be:

PW of repayment of principal 1,000(0.4529)	= $452.90
PW of 40 interest payments 15(27.355)	= 410.30
Valuation of bond to yield 4 per cent	= $863.20

There will be only a slight inaccuracy if a bond is valued on the basis of annual compounding, with the assumption that interest is paid only once a year. The inaccuracy is reduced by the fact that the inaccuracies in the present worths of the principal and interest are in opposite directions and tend to cancel each other.

When valuing any prospective future receipts, the proper procedure is first to estimate what the future receipts (and disbursements, if any) will be, and when each will occur. Then all that is necessary is to find the net present worth of these dollar values. Note that the 3 per cent interest rate of the bond valued in example 7 did not enter the problem directly. What was pertinent to this problem was the fact that the prospective receipts from the interest payments

were $15 at the end of each 6-month period for 20 years.

Frequently the problem is to find the prospective rate of return on a bond that is offered at a certain price. Published bond tables give this information for many periods and many interest rates and yields, but the problem cannot be solved directly from ordinary compound interest tables, which do not give directly the value of an unknown interest rate. In the absence of bond tables, the easiest way to find an unknown yield is to assume successive interest rates until the answer is found by the cut-and-try method.

5.7 EXAMPLE 8, CAPITALIZED COST

Sometimes the term "capitalized cost" is used synonymously with the term "present worth," without regard to the length of the study period, but more often capitalized cost means the present worth of perpetual service. The latter meaning will be used in this discussion. It is obvious that the capital recovery cost of an investment that lasts forever is merely the investment multiplied by the interest rate. The reverse must also be true, in the sense that the present worth (capitalized cost) of a uniform annual future series that lasts forever is the value of the annual series divided by the interest rate. Using the data of examples 3 and 6, the capitalized cost of structures E and F are as below:

The capitalized-cost calculations of this example indicate that E is better than F to the extent that the present deposit at 5 per cent required to take care of perpetual service with these structures, including both replacements and annual disbursements, is $745 less for E than for F. As $745(0.05) = $37, the results of examples 3, 6, and 8 are equivalent at 5 per cent compound interest.

Some comments should be made on the calculations of example 8. It was explained earlier that the capitalized cost of a perpetual uniform annual series is equal to the value of the series divided by the interest rate. Where one has a series of payments of equal amounts but with intervals greater than one year, it is a simple matter to convert this series to a uniform annual series. The perpetual series of renewals for structure E will require $6,000 every 10 years, and this requirement can be met by making a perpetual uniform annual series of payments into a sinking fund that will amount at 5 per cent interest to $6,000 at the end of every 10 years. This perpetual series (6,000 × 0.07950) may in turn be converted into the necessary capitalized cost by dividing it by the interest rate. Thus the capitalized cost of providing for the perpetual series of renewals of structure E will be $9,540 as calculated in example 8.

There is a still more direct way to determine in a single calculation the capitalized-cost requirements for both

Structure E

First cost		= $ 6,000
PW of perpetual series of renewals	$\frac{6{,}000(0.07950)}{0.05}$	= 9,540
PW of perpetual annual disbursements	$\frac{1{,}100}{0.05}$	= 22,000
Total capitalized cost		= $37,540

Structure F

First cost		= $20,000
PW of perpetual series of renewals	$\frac{15{,}000(0.02095)}{0.05}$	= 6,285
PW of perpetual annual disbursements	$\frac{600}{0.05}$	= 12,000
Total capitalized cost		= $38,285

the initial investment in structure E and also the series of perpetual renewals. In example 3, the capital recovery cost of the investment in the first structure E was found to be $6{,}000(0.12950) =$ \$777 per year. A perpetual series of \$777 per year will therefore be equivalent to the investment in the perpetual series of structures E, including the first structure E. The capitalized cost that is equivalent to this perpetual series will, of course, be $777/0.05 =$ \$15,540. It will be noted that this is equal to the sum of the first two items in the calculations for structure E in example 8, which is exactly what it should be.

It is evident from a comparison of examples 6 and 8 that in situations of this sort the calculations of the capitalized-cost method of example 8 are much less laborious than those of the present-worth method of example 6. The fact that this advantage of the capitalized-cost method can be secured only by making the generally unrealistic assumption of the perpetual-service requirement is not so serious an objection as it might seem to be at first glance. The capitalized-cost method would hardly even be considered unless the study period were quite long, and in compound interest calculations the difference between a long period and forever is surprisingly small. For example, even with as low an interest rate as 5 per cent, the capitalized costs of example 8 for perpetual service are less than 10 per cent greater than the present-worth costs of example 6 for a service of 50 years. Since the capital-recovery factor (the reciprocal of the uniform series present-worth factor) for infinite life is equal to the interest rate, it is a simple matter to determine the ratio of capitalized cost to present worth for any period of time and interest rate.

5.8 SELECTION OF PRESENT-WORTH INTEREST RATE

It was pointed out earlier in this section that a possible objection to the present-worth method is the fact that the average person does not realize the great difference in the mathematical solution that may result from what seems to be an insignificant difference in the interest rate. The selection of the interest rate is both important and difficult in engineering economy studies, no matter what method is used, but there can be no doubt that the selection of a reasonable interest rate when using the annual-cost method is made easier by the similarity of the problem to the way interest rates are set in other financial situations.

Present-worth problems are of two main classes. In one, the interest rate should be low, and in the other the interest rate should be high. If the problem is to set an interest rate for use in calculating the amount of an endowment fund that will provide a certain future annual income, the interest rate should be that rate which can be obtained from an investment in securities involving a minimum risk of loss. This will, of course, be a low interest rate.

On the other hand, if the problem is to set an interest rate for determining how much one can afford to invest in a machine that will afford a prospective future annual net saving in cost, the rate should be high enough to take care of the risks involved. In other words, one should ordinarily capitalize such prospective annual savings at a much higher interest rate than could be obtained from an investment in securities involving a minimum risk of loss.

6. RATE OF RETURN ON ADDITIONAL INVESTMENT

Many engineering economy studies involve comparisons where there are two or more alternatives with differing investments and differing annual costs. The problem in its simplest form involves the question of whether it is desirable to invest an additional amount now in order to secure certain prospective annual savings during the life of the investment. An examination of discussions on this subject indicates that most formulas that have been proposed

for solving this problem attempt to determine the rate of return that may be expected on the additional investment in the alternative having the higher first cost and the lower annual operating costs. (Some formulas approach the problem from a somewhat different viewpoint, and attempt to determine the time that would be required for the savings in annual operating expenses to "pay for" the additional investment in the alternative with the higher first cost and the lower annual operating costs; this will be discussed later in this article.)

As will be shown later in this discussion, it is possible to determine the rate of return on the additional investment in situations of this kind, but at best this is not a direct or simple computation. In spite of the great popularity of the formulas proposed for use in finding the rate of return on additional investments, the writer has never found one that is both economically sound and also simple enough to justify its use. Fortunately, there is no real need to use a formula in solving these problems; the annual-cost method discussed in an earlier article will ordinarily give information that is sufficient for making the decision, and can also be used indirectly to give the rate of return on the additional investment where it is really worth while to obtain that particular information.

6.1 EXAMPLE 9, RATE OF RETURN UNDER SIMPLEST CIRCUMSTANCES

This example will utilize the data of example 1, where the conditions of equal lives and zero salvage values make the determination of the rate of return on additional investment a comparatively simple matter. One way to compare the alternatives in this example is to note that for an additional present investment of $3,000 in machine B there will be prospective savings in cash disbursements of $500 per year during the 10-year period that represents the expected life of each machine. Under the somewhat unusual circumstances of this very simple example, the rate of return on the additional investment in machine B is evidently that interest rate for which the capital-recovery factor for 10 years is $500/3{,}000 = 0.16667$. There are no tables in which i is the unknown, but by interpolation between the 10-year capital-recovery factors (in Table 3.10) of 0.16275 for 10 per cent and 0.17698 for 12 per cent, we find that the rate of return on the additional investment in machine B is approximately 10.6 per cent. It should be noted that even in this extremely simple situation this rate of return of approximately 10.6 per cent was not found directly by means of a formula. In fact, the writer does not know of any usable formula that could be employed to get this rate directly.

6.2 EXAMPLE 10, RATE OF RETURN UNDER MORE COMPLICATED CIRCUMSTANCES

To be really useful, a formula or other method for finding the rate of return on additional investment must be usable under the general conditions of different lives and positive salvage values. In this example, the data of example 3 will be used. It is obvious that under the more complicated circumstances of example 3, it is not possible to calculate a capital-recovery factor corresponding to the rate of return on the additional investment in structure F, as was done in example 9. It is also obvious that the rate of return on the additional investment in structure F must be less than 5 per cent, because the annual costs at 5 per cent interest are greater for structure F than for structure E. Assume a rate of 4 per cent, for which the annual costs are:

Structure E

Cap. rec. cost 6,000(0.12329)	= $ 740
Int. on salv. val.	.....
Annual disbursements	= 1,100
Total annual cost	= $1,840

Structure F

Cap. rec. cost 15,000(0.06401)	= $ 960
Int. on salv. val. 5,000(0.04)	= 200
Annual disbursements	= 600
Total annual cost	= $1,760

It is obvious that the interest rate that will make the annual costs of the two structures equal must be between 4 per cent and 5 per cent. Interpolation shows the rate is approximately 4.7 per cent.

It is obvious that the method used in example 9 to determine the rate of return on the extra investment in machine B is a correct method, and also that the annual costs will be the same for machines A and B when calculated with an interest rate of 10.6 per cent.

It is not so obvious that the 4.7 per cent interest rate calculated in example 10 is the rate of return on the extra investment in structure F. It is evident that the prospective saving of $500 per year in annual disbursements with structure F will be sufficient to recover the additional investment in structure F, at some interest rate greater than zero, when consideration is given to the greater prospective life of structure F and its expected salvage value. At the interest rate that makes the annual costs the same for the two structures, the two alternatives are financially equivalent, and therefore this interest rate is the rate of return on the extra investment in structure F. (If examples 6 and 8 are recalculated, using the interest rate of 4.7 per cent found in example 10, both the present worths and the capitalized costs of these two examples will be found to be the same, further evidence that 4.7 per cent is the rate at which the additional investment in structure F is recovered through the annual savings due to the use of structure F.)

6.3 EXAMPLES 11 TO 13, APPROXIMATE RATE OF RETURN ON ADDITIONAL INVESTMENT

Space limitations prevent even a listing of the various formulas and other similar methods that have been proposed for determining directly the rate of return on an additional investment, where the alternative having the larger initial investment has lower annual disbursements during its life. As stated earlier, the writer does not know of any method that will determine this rate directly and that is also economically sound. This discussion will be limited to a review of one popular method in which the time value of money is completely neglected and which, as will be noted from examples 11 to 13, gives results that are quite different from the true rate of return as found by the compound interest methods of examples 9 and 10. In this approximate method, the annual cost of using each alternative is calculated by dividing the first cost less salvage value of each alternative by its estimated life (in effect, this is straight-line depreciation) and adding this to the average estimated annual cash disbursements during estimated life. The approximate rate of return is then found by dividing the saving in annual cost thus determined by the increased investment in the alternative having the lower annual cost.

Example 11. In this example, the data of examples 1 and 9 will be used. The average disbursements are evidently $3,200 per year ($700 for depreciation and $2,500 for annual cash disbursements) for machine A and $3,000 per year for machine B. If the saving of $200 per year thus found is divided by the additional investment of $3,000 in B, the rate of return on the additional investment appears to be 6.7 per cent. The true rate of return as found in example 9 is approximately 10.6 per cent.

Example 12. In this example, the data of example 2 will be used. Here the average disbursements are $2,100 per year for machine C and $1,800 per year for machine D, and the additional investment in machine D is $4,000. Hence the rate of return on the additional investment appears to be 7.5 per cent. If the method of examples 9 and 10 is applied to these data, it will be found that the true rate of return is approximately 9.2 per cent.

Example 13. In this example, the data

of example 3 will be used. Here the average disbursements are \$1,700 per year for structure E and \$1,200 per year for structure F, and the additional investment in structure F is \$14,000. Hence the rate of return on the additional investment appears to be 3.6 per cent. The true rate of return as found in example 10 is approximately 4.7 per cent.

A method that gives results so far from the correct results is certainly not a good method. It is sometimes argued that, since this method gives results that are always less than the correct results, the method is a conservative one. However, as will be noted from the results of examples 11 to 13, the method is very erratic in the percentage of error under different circumstances, and if one wishes to be conservative in such matters, it seems more reasonable to select a method that is more dependable.

This method is incorrect because the time value of money is neglected when calculating the average disbursements, including the investments, and because it is assumed that the investments remain undiminished during the study periods. Salvage values cause the error to be less percentagewise, as will be noted from the smaller errors of examples 12 and 13 as compared with the error of example 11.

Occasionally a method is used which is similar to this incorrect method, with the exception that some sort of average value is used for the additional investment. This average is generally considered to be one-half of the original value of the additional investment, but in a few rare instances there seems to be the same sort of adjustment by the factor $(n+1)/n$ as is used in determining the average interest rate in the approximate method of calculating average costs in examples 1 to 3. This sort of averaging seems never to be used where there are salvage values and can hardly do anything except add still another complication without really increasing the soundness of the method.

There are many other published methods that are supposed to give the rate of return on additional investment and that at first glance seem to do so. None should be used without a careful analysis of their economic soundness.

6.4 RATE OF RETURN ON ADDITIONAL INVESTMENT IS SUPERFLUOUS INFORMATION

In view of the great difficulty, if not the impossibility, of constructing a sound and simple method for obtaining directly the rate of return on the additional investment, it is fortunate that this information is really not of any importance. Even if this information were readily available, no decision could be made in any given situation until it was determined what the minimum attractive rate of return was. After the minimum attractive rate of return is once established, it is a very simple matter to make annual cost calculations similar to those in examples 1 to 3. If the annual costs thus found are less for the alternative with the larger investment, it is obvious that the rate of return on the additional investment is more than the minimum attractive rate of return, and that the alternative having the greater investment should presumably be selected. Ordinarily, any additional advantage which the alternative with the greater investment may have over the minimum attractive rate of return can just as well remain as so many dollars per year, as given in the annual cost solution. But if there is really an advantage in knowing the magnitude of the rate of return on additional investment, that can be found by methods like those of examples 9 and 10.

6.5 THE "PAY-OFF PERIOD" IS ALSO SUPERFLUOUS INFORMATION

Many formulas and other methods have been proposed that are intended to determine how long it will take for savings in annual operating expenses to pay for an additional investment in the alternative with the greater first cost.

Here again, it does not seem possible to obtain this information directly in any sound and simple manner. In addition, it is not always clear just what such a proposed method is supposed to accomplish. Sometimes all that is desired is the period during which the additional investment will be recovered without any return *on* the investment *during* recovery. At other times, the recovery period is supposed to be that period during which the investment will be recovered, *plus* a satisfactory return on the investment during recovery.

Fortunately, it is not really important to determine directly the so-called "pay-off period." Even if the information were readily available, it would be of no use until it could be compared with the proper pay-off period under the given circumstances. After a decision has been made on the minimum attractive rate of return and the maximum satisfactory pay-off period for a given study, it is a simple matter to make annual-cost comparisons such as examples 1 to 3. The results of these studies should be sufficient for making the decision, and can be modified in any way that may be desired.

7. CRITERIA FOR CHOOSING AN ECONOMY STUDY METHOD

Problems in engineering economy often involve differences in prospective receipts and disbursements at different dates. They are especially likely to involve a comparison of alternatives having different first costs and annual operating expenses. In order that such alternatives may be comparable, it is generally necessary to use economy studies that recognize the time value of money.

Because the problem is of particular importance in competitive industries, and is treated so fully in publications on the subject, previous articles have devoted much attention to comparisons where one of the alternatives has a greater first cost and lower prospective annual cash expenditures. Like most other problems in engineering economy, this particular problem may be solved by means of any of three methods; annual-cost, present-worth, or rate of return on additional investment. No one of these methods is inherently better than the other two, but each has advantages under certain circumstances. The following discussion is intended to assist in choosing a method in a given situation and also to assist in the use of the chosen method.

7.1 CONDITIONS FAVORING ANNUAL-COST METHOD

This method is especially desirable in comparisons where there are no differences in prospective revenues, and where the alternatives differ merely in such things as first cost, annual operating disbursements, prospective service lives, and salvage values. When making the annual-cost calculations, the interest rate should be the "minimum attractive rate of return," or, in other words, the rate of return that appears to be necessary to justify the particular investment in view of the risks involved in this investment. When comparisons are made by means of this method, the alternative having the lowest total annual cost will presumably be selected, and if this alternative has a greater first cost than some other alternative, the fact that its total annual cost is lower will prove that its annual disbursements are enough lower to give more than a satisfactory rate of return on the additional investment.

Where the study-period lives are 10 years or less, and particularly where there are no material differences in the study-period lives of the various alternatives, it is generally satisfactory to use the method of straight-line depreciation and average interest.

In spite of its great popularity in publications on the subject, the rate of return on additional investment method is not well adapted for use in this particular problem. This matter is discussed at considerable length in Art. 6.

7.2 CONDITIONS FAVORING PRESENT-WORTH METHOD

This method is particularly desirable when the problem is to place a present valuation on prospective future receipts. The determination of how much one could afford to pay for a bond in order to secure a desired yield is an excellent example, but there also are many others.

This method is also desirable in the comparison of alternatives having irregular series of receipts or expenditures, particularly comparisons of immediate and deferred investments.

7.3 CONDITIONS FAVORING RATE-OF-RETURN METHOD

In Art. 6, there is an explanation of the reasons why this method is generally not desirable for comparing alternatives where the alternative with the higher first cost has lower prospective annual operating expense. There are, however, some exceptions to this rule, as will be explained in Arts. 7.4 and 7.5.

The rate-of-return method is particularly adaptable to situations where the alternatives are to make an investment or to do nothing. In some such problems, it is possible to design a comparatively simple method that will give the information directly, but in many cases it will be necessary to employ a trial-and-error procedure, using either the annual-cost method or the present-worth method. Where successive increments of investment are possible, the rate of return on each such increment should also be calculated, as explained in Art. 7.5.

7.4 EXAMPLE 14, CONDITIONS PARTICULARLY FAVORABLE TO RATE-OF-RETURN METHOD

In spite of the statements made in Art. 6, there are many situations where the rate-of-return method is particularly desirable. One such situation involves proposals to reduce manufacturing costs by means of jigs and fixtures, or other tooling. In such cases, many of the objections to the rate-of-return method stated in Art. 6 are likely not to apply.

Example 14 involves a proposal to provide some special tooling for use in the manufacture of an article, where the rate of production has recently increased greatly. It is estimated that this tooling will cost \$1,200 ready to use, and that it will reduce the cost of article A by \$0.013 per piece. This tooling is useless for any other purpose and its installation can be justified only if the saving in the cost of article A will provide a sufficient rate of return on the investment in the tooling The present rate of production of article A is 30,000 pieces per year and there is no reason to expect that any change in the usage of this article will soon occur.

Because it is not considered to be economical to make the sort of economy study that would be used when considering the installation of major items of equipment, this company has a policy that items of tooling of the sort described in this example must show "gross" annual savings of at least 30 per cent on the investment. This 30 per cent rate is based on average past experience with investments of this sort and is supposed to cover return *of* and *on* the investment (depreciation and interest). Although the depreciation and interest factors are not separated, it is interesting to note that a capital-recovery factor of 30 per cent corresponds approximately to capital recovery in 8 years at 25 per cent, in 6 years at 20 per cent, in 5 years at 15 per cent, and in 4 years at 8 per cent.

In this example, the prospective saving is $30{,}000(0.013) = \$390$ per year, or $390/1{,}200 = 32.5$ per cent gross annual return on the investment. The tooling should be installed.

7.5 EXAMPLE 15, RATE OF RETURN ON SUCCESSIVE INCREMENTS OF INVESTMENT

Often in situations like that of example 14, there are several available ways to secure a reduction in present

cost. In such cases, each investment should meet the minimum requirement as to rate of return, and, in addition, each successive increment of investment should also meet this minimum requirement. This is illustrated in example 15, the data being as follows:

Five alternative schemes for reducing the manufacturing cost of a certain operation have been proposed in a plant where such proposals are required to show a minimum annual gross return of 25 per cent on the investment.

Scheme	Required Investment	Annual Cost Saving
A	$1,000	$400
B	1,200	460
C	1,500	520
D	1,600	545
E	2,000	600

The information required to solve this problem is given in the table at the bottom of the page.

From the viewpoint of return on total investment, each scheme meets the 25 per cent requirement, but schemes C and E must be eliminated because they do not meet the requirement that each increment in investment must show a minimum return of 25 per cent. At first glance, scheme D seems to be satisfactory, because it shows a return of 25 per cent on the increment in investment above the investment in scheme C, but this 25 per cent figure is meaningless, because it is based on the values for scheme C, which scheme has been proved to be unsatisfactory. Therefore, scheme D should be compared with scheme B with respect to extra investment and extra saving. This extra investment is $400 and the corresponding extra saving is $85, giving a return of $85/400 = 21.3$ per cent. As this is less than the required 25 per cent, scheme D must be eliminated, and scheme B should be selected.

8. ECONOMIC LOT SIZES IN MANUFACTURING

A correct understanding of the economic lot size problem is desirable both because of the importance of the problem itself and also because there are many other minimum-cost problems whose solutions are similar. The following discussion is adapted from that in a bulletin published in 1934.* Changes in interest rates since that time have made the 6 per cent rate used in this bulletin as the "cost of money" unreasonably high, but the 6 per cent rate is used in this discussion because the exact cost of money rate is not important and it is interesting to note the difference between lot sizes determined at a minimum attractive rate of return of 20 per cent and those determined when using a cost-of-money rate even as high as 6 per cent.

8.1 IMPORTANCE OF PROBLEM

Many mass-production industries manufacture in advance of sale and ship articles as desired from finished stocks stored in warehouses. Modern manufacturing equipment will ordinarily produce at a very rapid rate while operating but will also have high preparation costs. Manufacturers know very well that under such circumstances the best way to reduce unit preparation costs is to produce in large lots. But manufacturers do not always understand to what an extent large lots increase unit charges incident to storage, such as rental of storage space, insurance and taxes on finished inventory, return on capital invested in finished inventory, and increased risk of

* P. T. Norton, Jr., *Economic Lot Sizes in Manufacturing* (Blacksburg, Virginia: Virginia Polytechnic Institute, 1934).

Scheme	Investment	Saving	Return on Total Investment	Extra Investment	Extra Saving	Return on Extra Investment
A	$1,000	$400	40.0%	...	..	.....
B	1,200	460	38.3%	$200	$60	30.0%
C	1,500	520	34.7%	300	60	20.0%
D	1,600	545	34.1%	100	25	25.0%
E	2,000	600	30.0%	400	55	13.8%

loss due to deterioration or obsolescence of inventory. The last-named factor may result in excessive amounts having to be sold at heavy discounts in order to get rid of styles that have not proved popular.

This rather general failure to pay sufficient attention to the unit charges incident to storage is undoubtedly due to the fact that cost-accounting methods may be perfectly satisfactory for the purposes for which they are designed, but incapable of giving all the information that is required for establishing economic lot sizes. Unit preparation costs show up clearly on the cost-accounting records, whereas most of the costs incident to storage either do not appear at all in the accounting records or are not identified there as costs that vary with lot size. The unit charges incident to storage are none the less real and should be given full consideration. It will be shown presently that for the most economical size of lot the unit preparation costs are equal to the unit charges incident to storage. What should be aimed at is a size of lot which, by rapid turnover of capital invested in finished inventories, will reduce the unit charges incident to storage to the point where they do not exceed the unit preparation costs.

8.2 DERIVATION OF THE FORMULA

Economic lot size problems may be solved in several different ways. Many formulas have been developed for the purpose. Some are too complicated for practical use because their authors have tried to include every variable that has any effect. Others have limited usefulness because they do not include some variables of real importance. Many give lot sizes that are entirely too large because they use the interest rate on borrowed money instead of the minimum attractive rate of return when determining carrying charges on the investment in finished inventory. It is believed that the formula to be developed presently is simple enough to be understood and used by anyone, and also that it includes all the factors necessary for a correct solution of the problem; a satisfactory turnover of capital invested in finished inventory is obtained by charging investment in finished inventory with the minimum attractive rate of return, based on the risks involved in the storage of this particular inventory.

Although formulas are useful in solving this problem, it should be understood that the economic lot size may be found just as well by tabular or graphical methods, which have the advantage that they give not only the economic lot size but also the economic range, something that no formula can possibly give. In addition, tabular and graphical methods show the effect on total unit charges of any deviation from the economic lot size; information that is often of great value.

In the formula to be developed, let:

$Q =$ the lot size (pieces per lot)
$Q_e =$ the economic lot size (pieces per lot)
$S =$ total preparation cost per lot (dollars), including cost of preparing manufacturing orders, cost of setting up machines, and any other similar costs that are independent of the number of pieces in the lot
$P =$ pieces made per day
$U =$ pieces used per day
$N =$ days worked per year
$C =$ material, direct labor, and factory overhead per piece (dollars)
$A =$ cost of storing one piece for one year (dollars)
$B =$ taxes, insurance, etc. (per cent per year on inventory)
$I =$ minimum attractive rate of return on capital invested in finished inventory, risks considered (per cent per year)
$V =$ total amount charged against each piece (dollars) for:
(a) preparation costs,
(b) material, direct labor, and factory overhead,
(c) storage charges, including return on invested capital.

It can easily be proved that in the following derivation the preparation cost per piece may without error be neglected when figuring the capital tied up in finished inventory. The following deriva-

tion assumes that the total amount C will be charged from the moment production begins; other assumptions will be discussed later. As is customary, it will be assumed that the consumption rate is uniform; if the demand varies greatly between seasons, it may be desirable to compute the economic lot size for each season.

Under these assumptions, the maximum amount of capital tied up in finished inventory will be CQ dollars, and the average amount of capital thus tied up will be $CQ/2$ dollars. As there are NU pieces per year, the average amount of capital tied up *per piece* will be $CQ/2NU$ dollars.

Insurance and taxes must be paid on finished inventory, and the charge *per piece* for these items will be $BCQ/2NU$ dollars.

Cost accountants do not ordinarily include a charge for interest on capital tied up in inventory as part of the cost of a product. However, in studies of this sort, where different lot sizes result in different amounts of invested capital, it is necessary to consider this factor. It is only by making this charge at the minimum attractive rate of return that full consideration can be given to the important factor of capital turnover. On this basis, the charge *per piece* for return on invested capital will be $ICQ/2NU$ dollars.

It will be assumed that storage is in bins and that space must be reserved permanently for the largest number of pieces of each article that will ever be in storage. $(P - U)$ pieces will go into storage each day during production, which will continue for Q/P days. Hence the maximum number of pieces for which storage must be provided will be

$$\frac{Q}{P}(P - U) \quad \text{or} \quad Q\left(1 - \frac{U}{P}\right) \text{ pieces}$$

As it costs A dollars to store one piece for one year, and there are NU pieces per year, the cost *per piece* for providing storage will be

$$\frac{A\left(1 - \frac{U}{P}\right)Q}{NU} \text{ dollars}$$

The total charges *per piece*, incident to storage, are the sum of the three expressions just derived, and may be written

$$\left[\frac{(B + I)C + 2A\left(1 - \frac{U}{P}\right)}{2NU}\right]Q,$$

or KQ

where K is a constant representing the terms within the brackets. The total charges *per piece* will be

$$V = \frac{S}{Q} + C + KQ$$

This equation shows that the total charges against each piece are the sum of three parts: the preparation cost per piece S/Q, which varies inversely with size of lot; the approximately constant cost per piece C, for material, direct labor, and factory overhead; and the charges per piece incident to storage KQ, which vary directly with size of lot.

The economic lot size will obviously be the lot size for which V is a minimum. This may easily be found by tabular or graphical methods, but the simplest way is to find the first derivative and set it equal to zero.

$$\frac{dV}{dQ} = -\frac{S}{Q^2} + 0 + K,$$

and setting $\frac{dV}{dQ}$ equal to zero,

$$Q_e = \sqrt{\frac{S}{K}}$$

The approximately constant unit cost of material, direct labor, and factory overhead C does not appear in the final formula, but it does affect the economic lot size because of its effect on the value of K.

The economic lot size formula just derived may be written:

$$\frac{S}{Q_e} = KQ_e$$

which proves that for the economic lot size, the unit preparation charges S/Q_e are equal to the unit charges incident to

storage KQ_e. This relationship is useful when it is desired to solve a problem of this sort by tabular or graphical methods.

8.3 EXAMPLE 16, USE OF THE FORMULA

In order to illustrate the use of the formula, the economic lot size will be determined under the following conditions:

S = \$10.00
P = 1,000 pieces per day
U = 100 pieces per day
N = 300 days worked per year
C = \$0.10 per piece
A = \$0.001 per piece
B = 3% per year
I = 20% per year

Under these conditions, the value of K will be

$$\frac{(0.03 + 0.20)0.10 + 2(0.001)\left(1 - \frac{100}{1{,}000}\right)}{2(300)(100)} = \$0.00000041$$

and $$Q_e = \sqrt{\frac{10.00}{0.00000041}} = 4{,}940 \text{ pieces per lot}$$

8.4 TABULAR METHODS MAY BE USED IN PLACE OF THE FORMULA

By means of the formula, it has been a simple matter to determine that the economic lot size is 4,940 pieces per lot. The formula cannot, however, give either the total unit charges or the difference in total unit charges with some other size of lot. The simplest way to obtain this valuable information is to tabulate the values as is done in Table 3.13.

Table 3.13 shows that the minimum total unit charges amount to \$0.10404 at the economic lot size of 4,940 pieces per lot; also that the total unit charges are practically the same for lot sizes between 4,500 pieces and 5,500 pieces; and that for any lot size between 3,000 pieces and 7,000 pieces the total unit charges would not be more than one-half of 1 per cent more than at the economic lot size. Thus the lot size may ordinarily be varied to a considerable extent from the economic lot size without greatly increasing total unit charges. The fact that the lot size may ordinarily be reduced below the economic lot size without materially increasing the total unit charges is of great significance, as it enables a manufacturer to reduce his working capital requirements by reducing the amount of money tied up in finished inventory.

8.5 IMPORTANCE OF USING MINIMUM ATTRACTIVE RATE OF RETURN INSTEAD OF INTEREST RATE ON BORROWED MONEY

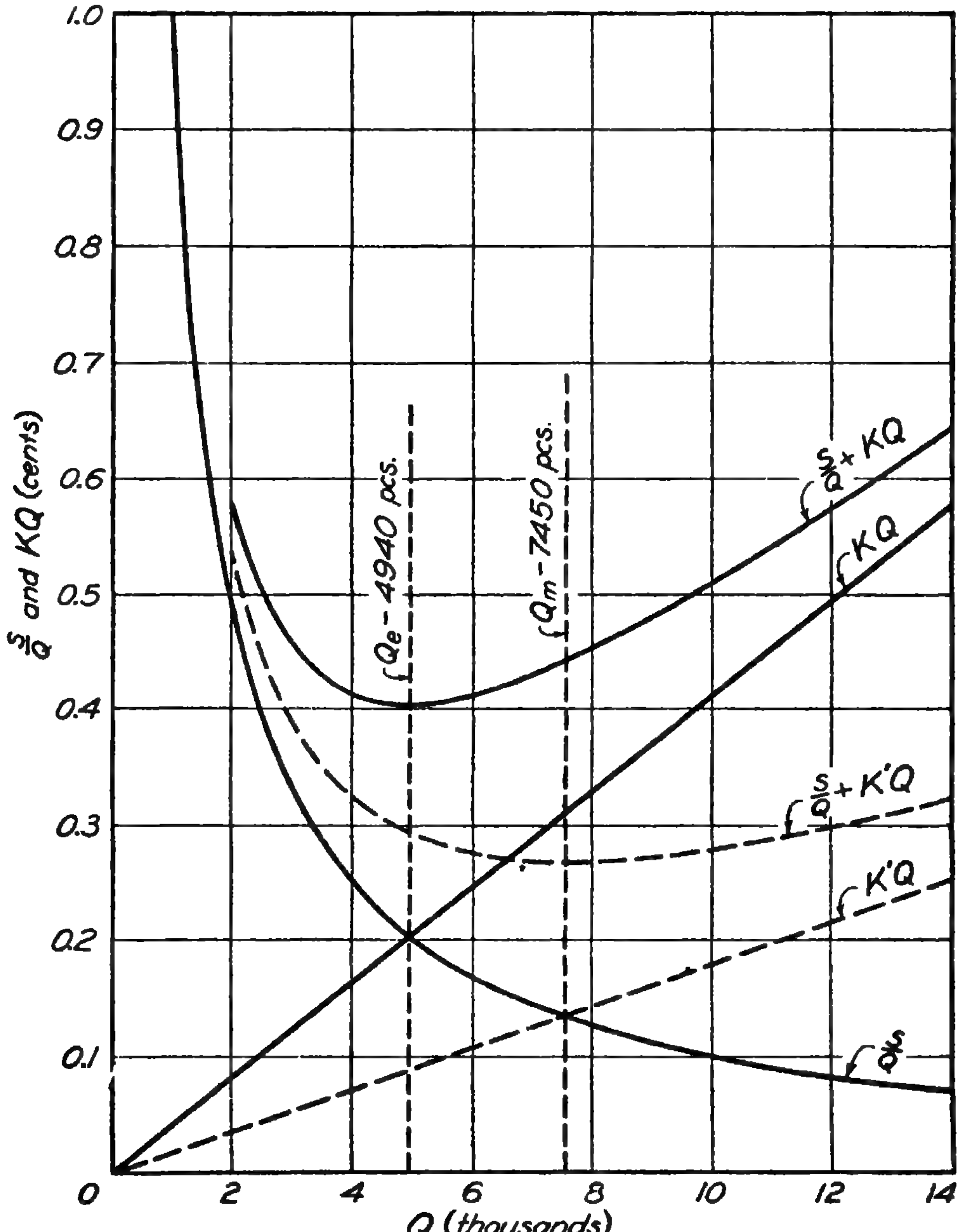
Many economic lot size formulas use the interest rate on borrowed money ("cost of money") instead of the minimum attractive rate of return. If as high an interest rate as 6 per cent is used in this example, the formula will give a value of 7,450 pieces per lot for what might well be called the "minimum cost lot size" However, this would not be a desirable lot size, as the turnover in capital invested in finished inventory would not be great enough to take care of the risks involved.

Figure 3.2 shows graphically the relationship between unit preparation charges and unit charges incident to storage for this example. The full lines are for the economic size determination, using 20 per cent per year for I. The broken lines show the incorrect result that would be obtained if an interest rate of 6 per cent per year were used. (The horizontal line that would give the constant value of \$0.10 for C in Figure 3.2 is omitted because it would not change the shape of any of the curves of Fig. 3 2 or affect any of the information obtainable from Fig. 3.2.)

TABLE 3.13 UNIT CHARGES FOR VARIOUS LOT SIZES OF EXAMPLE 16 *

Q (pieces)	Q (cents)	(cents)	(cents)	(cents)
1,000	1.000	10	0.041	11.041
2,000	0.500	10	0.082	10.582
3,000	0.333	10	0.123	10.456
4,000	0.250	10	0.164	10.414
4,500	0.222	10	0.184	10.406
4,940	0.202	10	0.202	10.404
5,500	0.182	10	0.225	10.407
6,000	0.167	10	0.246	10.413
7,000	0.143	10	0.287	10.430
8,000	0.125	10	0.328	10.453

* From Norton, *Economic Lot Sizes in Manufacturing*, Table 1, p. 15.



Norton, *Economic Lot Sizes in Manufacturing*, Figure 1, p. 18.

FIG. 3.2 DETERMINATION OF ECONOMIC LOT SIZE.

8.6 MODIFICATIONS OF FORMULA FACTORS

Factor K is a constant for any given set of conditions, but may be varied to take care of several different situations.

In the derivation of K for use in example 16, it was assumed that the total amount for material, direct labor, and factory overhead was to be charged at the moment production began. This is probably the situation in the majority of cases, but because certain manufacturing costs are not actually paid until some time after work is performed, it is often reasonable to assume that the investment in finished inventory is merely for that portion of a lot that actually goes into storage, in other words

$$Q\left(1 - \frac{U}{P}\right)$$

Under these circumstances, the *investment part* of K will be

$$\frac{(B + I)\left(1 - \frac{U}{P}\right)C}{2NU}$$

In the derivation of K for use in example 16, it was also assumed that storage space must be reserved permanently for the largest number of pieces of each article that ever was in storage. In many cases, storage space may be released for storing other articles whenever a shipment is made. Under these conditions, the total storage space requirements will be only half as much as in example 16 and the storage cost part of K will be

$$\frac{A\left(1 - \frac{U}{P}\right)}{2NU}$$

It is now possible to state the four expressions for K that will permit one to use the formula for any of these assumptions for investment charges and storage costs.

If it is assumed that the entire cost for material, direct labor, and factory overhead must be charged at the moment production begins, and that storage space must be reserved for the maximum number of articles ever in storage, then:

$$K = \frac{(B + I)C + 2A\left(1 - \frac{U}{P}\right)}{2NU}$$

If it is assumed that the entire cost for material, direct labor, and factory overhead must be charged at the moment production begins, but that any vacant storage space may be used for any article, then:

$$K = \frac{(B + I)C + A\left(1 - \frac{U}{P}\right)}{2NU}$$

If it is assumed that the only investment that need be considered is that represented by articles actually in storage, and that storage space must be reserved for the maximum number of articles ever in storage, then:

$$K = \frac{[(B + I)C + 2A]\left(1 - \frac{U}{P}\right)}{2NU}$$

If it is assumed that the only investment that need be considered is that represented by articles actually in storage, but that any vacant storage space may be used for any article, then:

$$K = \frac{[(B + I)C + A]\left(1 - \frac{U}{P}\right)}{2NU}$$

There are several other relationships that may be present in certain situations, but that are rarely given consideration in economic lot size discussions. Some of these are important because when they are present they may reduce the time and effort required to make the studies.

The consumption rate U is one of the most important factors in the formula. It is standard practice to assume that this factor is a constant during the period under consideration. This is a sufficiently accurate procedure in most cases, but where the demand is quite seasonal, it may be desirable to determine a different

lot size for each season, using the appropriate value of U in each case.

It will be noted that U appears in K in two places; in the denominator and also in the numerator as part of the expression $(1 - U/P)$. In many cases, U is so small when compared with P that $(1 - U/P)$ may be considered to be unity. Under these circumstances, it is evident that Q_e varies directly with $\sqrt{U}$. Where the assumption that $(1 - U/P)$ is unity is a reasonable assumption, it is a simple matter to modify the general formula to the form $Q_e = D\sqrt{U}$, where D is the value of Q_e found from the general formula $Q_e = \sqrt{S/K}$, when $U = 1$. The lot size for any value of U may then be easily determined by multiplying D by $\sqrt{U}$.

8.7 RESERVE OR EMERGENCY STOCK

Many manufacturers plan their production on the assumption that there will always be a certain number of pieces of an article in stock when the following order begins to enter storage. Many economic lot size formulas attempt to include this reserve or emergency stock as a factor, but this is clearly not a sound procedure. If sales and production programs are carried out in accordance with the estimates on which the economic lot size study was based, the use of a reserve stock will merely increase the number of pieces in stock at all times by the amount of the reserve stock. The added charges incident to the storage of the reserve stock, though real, do not in any way affect the economic lot size.

8.8 SUMMARY OF ECONOMIC LOT SIZE DISCUSSION

Lot sizes should not be made as large as possible in order to reduce unit preparation charges, but should be made as small as possible in order to obtain a high rate of capital turnover and to reduce the risks incident to storage. However, if lot sizes are too small, the increase in the unit preparation charges will more than offset the advantages gained from lower charges incident to storage. All manufacturers are keenly aware of the reduction in unit preparation charges that is caused by large lots, but few manufacturers seem to understand how much large lots really cost them in charges incident to storage, including all the risks involved.

Total unit charges increase very little for considerable reductions in lot size below the economic lot size. Since the amount of capital tied up in finished inventory varies directly with the lot size, a manufacturer with limited working capital resources may often use to advantage lot sizes somewhat smaller than the economic lot size. By so doing, he will reduce the amount of capital tied up in inventory without materially increasing total unit charges.

Capital tied up in finished inventory should be charged with the minimum attractive rate of return on such capital and not merely with the simple interest rate paid on borrowed money. This procedure will automatically take care of the problems of capital turnover and such risks incident to storage as obsolescence and deterioration.

Formulas are useful in the routine determination of the economic lot size, but do not show the difference in total unit charges that would result from using some other lot size. This information is important and may easily be obtained through tabular or graphical methods of solving the problem.

For the economic lot size, the unit preparation charges are equal to the unit charges incident to storage.

The economic lot size varies approximately as the square root of the consumption rate. This relationship makes it possible to redetermine quickly lot sizes for various consumption rates after the economic lot size has been determined for the normal consumption rate by means of the complete formula.

8.9 OTHER MINIMUM-COST PROBLEMS

Most of the ideas that have been expressed in the foregoing discussion of the economic lot size problem

apply also to the many other minimum-cost problems appearing in discussions of engineering economy. For example, in the derivation of the well-known Kelvin's Law for the economical size of an electrical conductor, the factors are the same as in the derivation of the economic lot size formula, with the exception that factor C does not appear directly in the Kelvin's Law derivation. As this factor becomes zero in the first derivative, the Kelvin's Law and economic lot size formulas have the same final form.

In companies where the economic lot size problem is important at all it is likely to be very important. This importance is usually due more to the fact that there are so many cases than to the great importance of any single case. Where these conditions apply, the formula approach may be better than the tabular or graphical approach in spite of the limitations in the kind of information that can be obtained from the formula solution. There are, however, many other minimum-cost problems that occur infrequently but that are very important when they do occur. In cases of this sort, the tabular or graphical method is certainly the better method, because of the greater amount of useful information that may be secured.

9. THE BREAK-EVEN POINT CONCEPT

There are innumerable cases in engineering economy where one alternative is more economical under one set of circumstances and another alternative is more economical under other circumstances. For example, it was shown in Art. 6 that the rate of return on an additional investment may be ascertained by finding the interest rate that makes the annual costs or the present worths of the two alternatives equal; that interest rate is the break-even point.

Break-even charts have often been used in highly mechanized industries to determine the rate of production below which losses may be expected and above which profits may be expected. In its broadest sense, this problem is always a problem in engineering economy, but there is sometimes a lack of understanding of the great differences between the solutions of this problem for an existing plant and for a proposed plant. The fundamental basis for these differences is explained in Art. 13, under the discussion of sunk costs.

An idea of the great variety of break-even point problems may be obtained from the following list of such problems discussed by Grant:*

The break-even point as a dimension.
The break-even point as an expected life.
The break-even point as a justifiable investment.
The break-even point as a capacity factor.

Many formulas have been proposed for determining break-even points, but in most cases it will be found that tabular or graphical methods give more and better information, without requiring much more time or effort.

10. IMMEDIATE VS. DEFERRED INVESTMENTS

When it seems reasonable to anticipate that growth of some sort will require additional capacity in the future, there is often the problem of deciding how much additional capacity it is economical to provide immediately. It is obvious that piecemeal construction, where additions are provided only when it is necessary to increase capacity, is not ordinarily as economical as a planned construction program. This is due to many factors, including the fact that larger units are likely to be more satisfactory than smaller units, from the viewpoint of both first cost and operating costs.

When making an engineering economy study to determine how great a present

* Grant, *Principles of Engineering Economy,* 3rd ed., pp. 236-239.

investment is economical, in comparison with the alternative of deferring at least part of the investment, present-worth calculations seem to have several advantages over annual-cost calculations. The selection of the interest rate is one of the most important decisions in studies of this sort; it was pointed out in Art. 5.8 that what seem to be small differences in interest rates sometimes make great changes in the comparisons of alternatives.

Grant makes the following observations with respect to this problem:*

> Generally speaking, in any borderline case the irreducible factors are favorable to the alternative which involves a deferred investment rather than to an immediate investment with considerable excess capacity. This is particularly true if the interest rate used in the study has been the average cost of capital to an enterprise, without any increase to allow for a margin of safety. Unless the prospective rate of return is sufficiently higher than the cost of capital to justify a risk, that risk should not be undertaken.
>
> One irreducible factor favorable to the deferred investment is the possibility that the forecast growth may never materialize, and thus the excess capacity may never be needed. Another such factor in many situations may be the difficulty of securing investment funds with the resulting pressure to keep all investments to a minimum. Still another factor in some cases may be the possibility that anything installed in the future may be superior, or somehow better adapted to the needs of the service, than excess capacity installed at present in advance of such need.
>
> On the other hand there is a nuisance aspect to many deferred investment plans which is favorable to immediate construction with considerable excess capacity. This is particularly true with regard to public utility services which must be placed underground in paved streets so that any addition to them requires cutting through the pavement and repaving.

* Grant, *Principles of Engineering Economy*, 3rd ed., p. 267.

11. AMOUNT OF UTILIZATION OF A FIXED ASSET

Because the investment costs of such things as manufacturing equipment depend on time rather than on the degree of utilization, the greater the utilization the less the unit costs of product or services. This may have a significant effect on a comparison of alternatives that differ considerably in the relative importance of investment costs and annual disbursements.

For example, it may be economical in the long run to pay much more money for a high-efficiency motor, if the motor is to operate most of the time, but better to buy the cheapest available motor, with a very low efficiency, if the motor is to operate only occasionally. There are a very large number of seemingly different problems in engineering economy where this principle should be recognized when making a study.

An error that is frequently made when comparing several machines is to compare them on the basis of their unit costs for producing an article, with each machine operating at its capacity. What obviously should be done is to determine first what amount of product will be needed, and next what it will cost to produce that amount with each machine. Any available capacity beyond the required amount is an irreducible in favor of the machine with the extra capacity, but should not enter into the actual cost calculations of the study itself.

12. INCREMENT COSTS

In engineering economy studies, it is the prospective differences between alternatives that are significant when making a decision. No one would be likely to dispute the statement made in the preceding sentence, but unfortunately many errors are made in practice because of a failure to understand just what are the prospective differences between alternatives in any given situation. A case in point has to do with what are usually called "increment costs."

In engineering economy, the increment-cost concept often goes somewhat beyond a strict definition of the term, and in this discussion the use of the term will be explained rather than merely defined. Suppose, for example, that a certain domestic electric rate is as follows:

Service charge of $1.00 per month regardless of use.

4 cents per kw-hr for first 100 kw-hrs per month.

2.5 cents per kw-hr for the next 100 kw-hrs per month.

1.5 cents per kw-hr for all over 200 kw-hrs per month.

A certain family uses an electric range for cooking, and the monthly electric bills have been varying from about $7.00 in July for 180 kw-hrs to about $9.30 in January for 320 kw-hrs, with an annual cost for electricity of about $100. It is estimated that during an average month the electric range consumes 120 kw-hrs. The monthly bills for electricity are considerably higher than for neighboring families who cook with gas. The present range must be replaced and the householder is attempting to determine the operating cost of the electric range, which he suspects to be more than that of a gas range It is obvious that what is desired is the increment cost of operating the electric range, or, in other words, the cost in any month when using the electric range less the cost for that month if the electric range were not used.

Because of the structure of the rate schedule, the increment cost of using the electric range is quite different in different months, being $3.60 for July and only $1.80 for January, under the stated conditions. The only really safe way to determine what the cost of electricity is for operating this range is to calculate separately the monthly electric bill with and without the range. Calculations of this sort often give some surprising results for certain types of increment costs.

Much could be written about the many different kinds of increment costs, but that does not seem necessary here, because most of these different situations will be discussed under some other characteristic. What is very important is the rule that it is the prospective differences between alternatives that are significant when a choice is to be made between the alternatives. Formulas and other similar methods are sometimes used to obtain directly the differences between the alternatives, but (as in the electric bill example previously stated in this article) the safest way to determine the differences between alternatives is to determine first the magnitudes of the various alternatives and then to get the differences by simple subtraction.

13. SUNK COSTS

Grant explains the sunk-cost concept as follows:*

Once the principle is recognized that it is the *difference* between alternatives that is relevant in their comparison, it follows that the only possible differences between alternatives for the future are differences in the future. Any decision regarding a course of action for the future starts from now. Whatever has happened up to date has already happened and cannot be changed by any choice among alternatives for the future. This applies to past receipts and disbursements as well as to other matters in the past.

From the viewpoint of an economy study, a past cost should be thought of as a *sunk cost,* irrelevant in the study except as its magnitude may somehow influence future receipts or disbursements or other future matters. Although this principle that a decision made now necessarily deals with the future seems simple enough, many people have difficulty in accepting the logical implications of the principle when they make decisions between alternatives. This seems particularly true when sunk costs are involved. Although some of the failures to recognize the irrelevance of sunk costs involve a misuse of accounting figures, these mental obstacles to clear reasoning are by no means restricted to

* Grant, *Principles of Engineering Economy,* 3rd ed., p. 330.

people who have had contact with the principles and methods of accounting.

13.1 EXAMPLE 17, IRRELEVANCE OF A PAST DISBURSEMENT

Jones has decided to invest $1,500 in a business venture and is faced with the problem of raising the necessary cash. He has two alternatives: he owns 20 shares of common stock that he can sell at the present market value of $75 per share, or he can use a life insurance policy as the security for a 6 per cent loan. Jones estimates that the dividends on the stock will continue for an indefinite period at the present rate of $4.50 per share per year, so there will apparently be no difference between the interest cost of $90 per year on the loan and the $90 per year dividends on the stock that would be given up if the stock were sold.

Not being able to decide between the two alternatives, Jones seeks advice from a friend, who tells him that his decision should be based on whether the price he paid for the stock was more or less than the present market value of $75 per share; that the stock should be sold if the sale would "show a profit," but not if the sale would "show a loss."

At first glance, this argument seems plausible enough and there can be no doubt that this unwillingness to accept a loss is responsible for many of the misconceptions with respect to sunk costs and the irrelevance of past disbursements. Nevertheless, it is obvious that the cost of the stock should not in any way influence the decision on whether the stock should be sold or retained. The decision should be based solely on Jones' opinion as to future values for the stock. A book profit or loss should never influence a decision with regard to a sale. (Because profits are usually taxable and losses may within certain limitations reduce taxes, a decision concerning which assets to sell or whether to sell may depend on the tax consequences of the various alternatives, but this does not in any way nullify the rule that past disbursements are irrelevant.)

13.2 EXAMPLE 18, IRRELEVANCE OF BOOK VALUE

An automatic lathe with a first cost of $4,500 installed is being considered as a replacement for a 10-year-old turret lathe which originally cost $3,000, and which has been depreciated at the rate of $120 per year, so that its present book value is $1,800. The company would have no other use for the turret lathe if it were replaced in its present work, but it can be sold for $1,500.

This replacement study will be completed in example 20 of Art. 17, in the discussion of retirements and replacements. The present discussion will be limited to the problem of what to do with the $300 difference between the book value and the realizable value of the turret lathe.

Many writers on the subject insist that where the book value of a present asset is greater than its realizable value the difference between the two values should be added to the investment in the proposed asset, thus forcing the proposed asset to show savings that will recover both its own investment and also this so-called "loss due to replacement." These persons claim that the proposed asset should be made to bear this added burden because the "loss" is due to the replacement and takes place at the time of the replacement.

It requires only a brief consideration of the subject to prove that the book value of the present asset should receive no consideration whatever in a replacement study. The first cost of $3,000 for this present asset was spent 10 years ago, and no decision to retire or retain the asset can change either the amount or the time of this disbursement. The depreciation charge of $120 per year was merely a time allotment of the $3,000 investment, which in depreciation accounting is considered to be a prepaid expense of service during the life of the asset. No attempt is made in depreciation accounting to have book values *during life* agree with any sort of values, realizable or otherwise. Further discus-

sion of the differences in the aims of accounting allocations and engineering economy studies will be found in Art. 14.

Further evidence that this $300 difference between book value and realizable value should not be considered in any way in the replacement study may be found in the fact that depreciation accounting does attempt to charge off during life the entire difference between first cost and salvage value, the latter being the realizable value of $1,500 in this example. It is obvious that book value would always be realizable value at the time of a replacement, if lives and salvage values could be estimated accurately at the beginning of life, which it is not possible to do. (In Art. 16, in the discussion of the income tax aspects of depreciation, it will be shown that it has generally not been permissible since 1934 to charge off for tax purposes the so-called "losses on premature retirement.")

As explained in the preceding paragraphs, there are several conclusive reasons why both the book value and any difference between book value and realizable value should be disregarded in making economy studies. But the really important reason is that in such studies only future receipts and disbursements are relevant. It is the realizable value of the present asset (the highest of such things as scrap value, second-hand value, or value to the owner for some other purpose) that should be used as the investment in the present asset when making a replacement study.

Some of the errors in theory with regard to these matters are probably caused by an unfortunate use of words in defining both depreciation and book value. Grant and Norton discuss this as follows:*

> Modern writers on semantics have emphasized how readily one may be misled by words or phrases that have unfavorable associations. Two such phrases may be partly responsible for some of the confusion that exists in the interpretation of the depreciation accounts. One is the common definition of accounting depreciation as "loss in value." The other is the common description of unamortized cost as "unrecovered investment." "Loss" has an unpleasant sound that somehow makes depreciation seem worse than other operating expenses. . . . Depreciation accounting does not relate to value at all except as value may be defined in the neutral sense as any money amount that may be associated with property. "Unrecovered investment," despite its use by the Bureau of Internal Revenue, is an inaccurate description of unamortized cost. In some cases the investment in an asset actually may be recovered in its first few months of service, and in other cases it may never be recovered; neither fact has any relation to the depreciation that has been recorded on the books. (Even if unamortized cost really were unrecovered investment, it would not be relevant in a replacement economy study; the only differences between alternatives that properly enter into an economy study are future differences.)

* E. L. Grant and P. T. Norton, Jr., *Depreciation* (New York: The Ronald Press Company, Inc., 1955), p. 311.

14. INCORRECT INFERENCES FROM ACCOUNTING APPORTIONMENTS

Grant explains the limitations of accounting as a basis for estimates in economy studies as follows:*

> Generally speaking, the accounts of an enterprise constitute the source of information which has the greatest potential value in making estimates for economy studies. Nevertheless, the uncritical use of accounting figures is responsible for many errors in such estimates. There are a number of important differences between the point of view of accounting and that which should be taken in an economy study.
>
> Accounting involves a recording of past receipts and expenditures. It deals only with what happened regarding policies actually followed and is not

* Grant, *Principles of Engineering Economy*, 3rd ed., p. 22.

concerned with alternatives that might have been followed; it is concerned more with average costs than with differences in cost. It involves apportionment of past costs against future periods of time, and apportionment of joint costs between various services or products. It does not involve consideration of the time value of money.

Engineering economy, on the other hand, always involves alternatives; it deals with prospective differences between future alternatives It is concerned with differences between costs rather than apportionments of costs. It does involve consideration of the time value of money.

The statement is sometimes made that economy studies are merely a matter of accurate cost accounting. Such a statement involves a failure to comprehend these fundamental differences in point of view. . . .

The principle emphasized [here] is that it is always *differences* which are significant in economy studies, and that the concept of cost, in order to be a useful guide to business decisions, must be related to specific alternatives to be compared. The diversity of alternatives which must be compared in business situations is such that no routine systematic procedure can be expected to give directly the "cost" figures which are needed for all comparisons.

14.1 EXAMPLE 19, TO MAKE OR TO PURCHASE

This example records an actual experience of the writer some years ago when he was being shown by the plant manager through a large mass-production furniture factory. This was one of several such factories operated by a very successful company with very progressive top management. There was a well-planned cost-accounting system employing the most modern techniques, which probably gave very good information concerning the cost of the various articles, but which certainly was not adequate for the purpose for which its information was used in the decision recorded in this example.

In a lean-to off the machine room were four carving spindles which had evidently not been used for some time In answer to a question, the plant manager stated that the same four men who had formerly operated these spindles on a time wage basis were still producing the ornaments used by this company, utilizing second-hand rented spindles in a rented shed located in the same city. Further questioning developed the information that without working any harder than previously these four men were making more money, while the company was buying the ornaments cheaper than they had manufactured them. When asked how this could be, the plant manager stated that it was because they had a high overhead rate in this highly mechanized factory, whereas the four men had very little overhead in their operations with rented spindles in a rented shed.

Naturally, the writer then asked how the decision to discontinue manufacturing the ornaments had reduced to the slightest extent the *total overhead expense* of the factory. The factory manager replied that this had been bothering him, but that the head of the cost-accounting department had assured him that their method of figuring costs was correct and that they really were saving money by buying the ornaments. From further information furnished the writer by the plant manager, it was apparent that there had been no real decrease in total overhead expense as a result of this decision to buy the ornaments. Even the supervision had not been reduced to any great extent, because one of the four men had previously acted as a sub-foreman over the group. It seemed that the expense in the office incident to buying the ornaments was at least as great as the former expense in the production control department.

There was one feature of this cost-accounting system which, while satisfactory for the main purpose of the system, made it almost certain that any decision of this sort would be an incorrect decision. Because no repair parts

had to be costed separately and all complete articles utilized the facilities of each department approximately to the same degree as their direct labor cost in each department, this company followed a rule quite common in the furniture industry of basing the charge for factory overhead on direct labor cost, using a single plant-wide overhead rate. This practice made the overhead cost of manufacturing the ornaments seem much greater than it actually was, because the wage rates of the highly skilled men who operated these carving spindles were much higher than the average for the plant, while the overhead expense per man-hour for these inexpensive spindles was very much less than the overhead rate per man-hour for the many very expensive automatic machines that were used in this highly mechanized factory.

There could hardly be errors in the use of cost-accounting information more horrible than the one illustrated in this example, but the writer has found many cases that are nearly as bad in theory. This is the sort of error that could not possibly have been made by the men who founded these modern manufacturing companies. Most of them knew little or nothing about the principles that should govern either accounting procedures or engineering economy studies, but they did realize that the best and safest way to handle decisions of this sort was to determine as completely as possible the differences between the alternatives being considered. Those men were closer to the operations being performed than is the average theorist of today; it will be noted that it was the plant manager, who did not claim to know anything about cost accounting, who was troubled about a decision made by a man who was an expert in cost accounting, but who probably did not know the difference between a carving spindle and a double-end tenoner. Modern industry has become so complicated that we simply must use these highly developed management procedures, but there is no safe way to apply their principles automatically or by formula.

15. APPRAISALS: MEASURING THE DISADVANTAGES OF OLD ASSETS AS COMPARED WITH NEW ONES

Appraisals are made for many different purposes and in many different ways. As is true of so many other problems in the general field of engineering economy, the purpose for which the appraisal is made governs to a large degree the procedure that should be used. For example, the conventional reproduction cost new of an identical property, less straight-line depreciation, seems to work quite well for fire insurance purposes, but not at all well for most other purposes for which commercial appraisals are made.

In general, an industrial property does not have a value inherent in itself and separate from its use. If, therefore, it is desired to appraise an existing property, the first step should be to determine the most economical substitute property that could produce the desired service, and then to find the value for the existing property that would make its annual costs equal to those of the most economical substitute.

Methods for making this sort of appraisal are explained by Grant and Norton, who also make the following statements with respect to some paradoxes in this field:*

> Many paradoxes arise in the application of this equal annual cost viewpoint to replacement cost appraisals:
>
> 1. Often the appraised value of a plant as a whole should be less than the sum of the appraised values of its parts. The substitution of an entire new plant of radically different design may indicate many economies not possible in contemplating the most economical replacement asset for each part of the plant without any general change in the plant design or arrangement.
>
> 2. The more rapid the prospective fu-

* Grant and Norton, *Depreciation*, pp. 270-276. For other information on appraisals and the general concept of value, see J. C. Bonbright, *Valuation of Property*. New York, McGraw-Hill Book Company, Inc., 1937.

ture obsolescence, the more valuable may be the present obsolescent asset. Prospective improvements in design of new assets or prospective changes in service requirements may reduce the appraisal depreciation of existing old assets. For instance, . . . the prospect of further design improvements would reduce the expected life of the new asset. . . . This in turn would increase the equivalent uniform annual costs during the life of the new asset and would therefore increase the appraised value of the old asset.

3. In some cases, as time goes on, the appraisal depreciation of an old asset may become less as compared to a specific new one. If engineering ingenuity permits its better adaptation to the present service, the value of an old asset may increase with time even without price-level changes. For instance, developments in materials handling by lift trucks . . . have served to decrease the value inferiority of . . . certain brick buildings to . . . mill-type steel-frame buildings. . . . .

4. Appraisal depreciation may be negative; in other words, the appraised value of an old asset may be greater than the cost of the most economical substitute asset. For instance, if the most economical substitute is a new 18-inch pipe line, the lower pumping costs of an old 24-inch pipe line might give it a value superiority to the new pipe line.

5. Appraised values may be negative. The value inferiority of the old asset may be greater than the cost of the most economical substitute. . . . This simply means that it would pay to make an immediate replacement.

6. The less the contemplated service, the greater may be the appraised value. Although the most extreme instance of this seems to arise when appraising a plant used merely for stand-by purposes, it should be emphasized that the most economical plant for stand-by service may be quite different from that for regular operation.

16. DEPRECIATION

The following discussion of this complicated problem will be limited to those aspects of the subject that are of particular interest to industrial engineers, accountants, and the financial officers of corporations. It will not discuss in detail the bookkeeping problems involved in handling depreciation charges on the books.*

16.1 ECONOMIC VS. TAX ASPECTS OF PROBLEM

Many of the obstacles to a better understanding of depreciation fundamentals are caused by the fact that the problem is generally approached from the tax viewpoint. Depreciation is essentially an economic problem and should be studied as such. However, with high tax rates, decisions must be made with one eye on the tax collector.

There is no real understanding concerning the depreciation practices that actually were used prior to 1934 in the manufacturing industries. It is often stated that the straight-line method is the best method because we have always used it and it is the simplest method. It will be shown later in this discussion that neither of these statements is strictly true.

There is still no general understanding of the changes in Treasury depreciation tax practice that were made in 1934, or of the reasons for these changes. For example, it is still often stated that a principal advantage of the item method of handling depreciation is that this method enables "losses on premature retirement" to be written off at time of retirement. Such deductions have been prohibited by the tax regulations since 1934, except in very unusual situations. This failure to understand one of the more important changes that were made in 1934 has undoubtedly cost many companies a lot of money in the keeping of useless records, and, what is even worse, has prevented many taxpayers from using more realistic arguments

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* See Grant and Norton, *Depreciation*, for a full discussion of the economic and tax aspects of depreciation, including various methods of handling depreciation on the books

when seeking a liberalization of depreciation tax practice.

There were several reasons for this ignorance on the part of so many persons. During the depression years of the 1930's, few assets were retired, because few new assets were being installed and most taxpayers kept hoping that the demand for their products would increase to the point that all their assets could be used. During World War II, still fewer assets were retired, because all available facilities were required to handle the great demand for goods; this situation continued to a very large extent in the years immediately following World War II. In addition, there was such a great delay in the auditing of tax returns that many years sometimes elapsed before a taxpayer learned that certain deductions were not permissible. Finally, in some cases, where the amount was small, the examiner may not have been aware of the exact nature of the particular deduction.

16.2 PRACTICE PRIOR TO 1934

It is convenient to use 1934 as a reference date in depreciation discussions because most of the important changes that gradually occurred after 1934 were caused in large measure by the 1934 change in Treasury tax practice.

Depreciation practice prior to 1934, for both financial and tax purposes, was a satisfactory practice largely because it was not what it superficially appeared to be. The method in general use was called "straight-line depreciation," but in most cases the rates used were based on lives much shorter than actual lives. For example, in the manufacturing industries, a 10 per cent rate was commonly used for all machinery, although it must have been evident to everyone that average service lives were much longer than the 10 years which corresponded to this 10 per cent rate. In addition, the item method was generally used, under which any remaining undepreciated balance was charged off at time of retirement in those cases where retirements took place before the end of the estimated life. Moreover, depreciation charges ceased at the end of the estimated life for the larger number of assets whose actual lives were greater than the estimated life. The Treasury permitted this method to be used on income tax returns because the Treasury was primarily interested in seeing that depreciation charges ceased when the first cost of an asset had been charged off. It is significant that these higher pre-1934 depreciation rates were used by businessmen for both financial and tax purposes at a time when tax rates on business profits were so low that they had almost no affect on decisions concerning depreciation rates.

The pre-1934 practice was a very good practice because it charged off the investment in an asset more rapidly in the early years of life, when such factors as obsolescence cause the value to the owner to decrease most rapidly. In addition, new assets are likely to be used more than old assets. Old assets are often held merely for occasional or stand-by service, during which they have little or no opportunity to recover for their owners any of the investment that was originally made in them.

16.3 PRACTICE FROM 1934 TO 1953

In December 1933, a congressional subcommittee proposed, as a means of increasing revenue, that an arbitrary reduction of 25 per cent be made in the depreciation allowances of all taxpayers for the years 1934, 1935, and 1936. The Treasury opposed this arbitrary reduction, but stated that its own studies indicated that the past depreciation rates of many taxpayers had been excessive, because a continuance of such rates would permit these taxpayers to recover completely the basis of their assets before the end of the actual lives of these assets. The Treasury estimated that a tightening up of its own practice (without any change in the law

itself) would produce at least as much additional revenue as the $85,000,000 per year that had been expected from the proposed 25 per cent reduction in all depreciation allowances.

The alternative proposal of the Treasury was accepted by the Congress and no change was made in the law itself. Thereupon, the Treasury issued *Treasury Decision 4422* and *Mimeograph 4170*, which put into effect the change in Treasury depreciation tax practice.

The evolution in Treasury thinking concerning depreciation, and the reasons for the 1934 change in Treasury practice, can best be understood by reference to the 1920, 1931, and 1942 editions of *Internal Revenue Bulletin "F." Mimeograph 4170* (and later the 1942 edition of *Bulletin "F"*) specifically prohibited the deduction of so-called "losses on premature retirement." This was a complete change from the practice set forth in the 1931 edition of *Bulletin "F."* It really indicated a change for tax purposes from item accounting to group accounting. The complete change in viewpoint may not have been understood even by the Treasury officials; although *Mimeograph 4170* prescribed the group method, almost everything in it seems to call for information concerning individual items. It was not so stated, but the 1934 change in practice really indicated an acceptance by the Treasury of the statistical approach to life estimates of physical property units with straight-line rates based upon full service lives.

Such straight-line depreciation, which the Treasury attempted to enforce after 1934, implies that an asset with a life of 20 years has as much earning power in its 20th year as in its first year. This is obviously not so in most cases, because of obsolescence and the fact that as assets grow older they tend to be used less intensively. In fact, in many cases assets are used very little during the last few years of life, being retained merely for occasional or stand-by service. Under Treasury rules, the life of an asset does not come to an end until it is actually retired, and any years of stand-by service count just as much in determining the depreciation rate as do the first few years of life. In most cases, if investments in depreciable assets are to be recovered at all through the operations of these particular assets, the investments must be recovered during that portion of the lives when the assets are used in what may be called primary service.

16.4 STRAIGHT-LINE ITEM METHOD

Printed discussions in textbooks and handbooks, and interviews with engineers, accountants, and businessmen, indicate that most persons concerned with the depreciation problem believe that the straight-line method has been used almost exclusively for many years past in the competitive industries of the United States. This is simply not so. It is true that the method used today in most companies in the competitive industries is called "straight-line depreciation," and this name goes back for many years. But until 1934 the method carrying this name made no attempt to distribute the cost less salvage value over the full service life of an asset. The rates used were almost always greater than the rates corresponding to full service lives.

Nor is the straight-line method the simplest method to use, if full consideration is given to mortality dispersion and the fact that, with very few exceptions, post-1934 Treasury practice did not allow so-called "losses on premature retirement" to be charged to expense in year of retirement. This particular feature of post-1934 Treasury practice means that group depreciation accounting must be used for tax purposes no matter how the taxpayer handles depreciation for his own financial purposes. If group depreciation is used for tax purposes, it is doubtful if there are any advantages of the item method that would justify the average taxpayer in using the item method merely for his own financial purposes.

16.5 ITEM ACCOUNTING VS. GROUP ACCOUNTING

The following oversimplified example will illustrate the normal mortality characteristics of a group of supposedly identical assets, and will explain why post-1934 Treasury regulations did not ordinarily permit so-called "losses on premature retirements" to be charged off at time of retirement.

Assume that a group of 15 identical assets are installed at the same time and that the actual average service lives of these assets will be 10 years. It is normal for some of these assets to have lives shorter than 10 years and for others to have lives longer than 10 years. Assume that the actual service lives are as follows:

Number of Assets	Age at Retirement	Service Years Obtained
2	8	16
3	9	27
5	10	50
3	11	33
2	12	24
Total 15		150

This table proves that the average life of these 15 assets is 10 years, and that the owner receives from them a total of 150 service years, which is just what he should obtain from 15 assets having an average life of 10 years. Because this sort of mortality dispersion is the normal situation, there is no "premature retirement" when the assets are retired at ages of 8 and 9 years. It is for this reason that after 1934 the Treasury did not permit the writing off for tax purposes of these so-called "losses on premature retirement." (Differences between book value and salvage value may be written off on retirement where the retirement is caused by a casualty.)

If the straight-line group method is applied to the 15 assets just described, the entire investment will be charged off by the time the last asset is retired, if a 10 per cent rate is used.

Not only is the group method the normal method because of such things as mortality dispersion, but in addition it is the simplest and least expensive method. However, if the straight-line group method is used, the method will be a simple and economical method only if the actual average service lives agree closely with the estimated lives used in setting the depreciation rates for the various groups. In most cases, changes must be made in depreciation rates because of changes in average service lives or errors in estimating service lives. Each analysis to revise depreciation rates in the straight-line group method requires an age distribution of the dollar values of assets in the plant account and an estimate of the average remaining life of the assets in each age group. In the manufacturing industries, there is seldom enough information to enable such rate revisions to be made on any logical basis.

16.6 DEPRECIATION METHODS PERMISSIBLE UNDER THE INTERNAL REVENUE CODE OF 1954

The 1954 Federal tax law in the United States included a number of changes relative to the tax treatment of depreciation. As alternatives to the straight-line method based on full service life (the standard for the previous twenty years), taxpayers were given the option of using several other methods. The newly permissible methods made it possible to write off the cost of fixed assets more rapidly during the early years of life. Permission to use these methods was limited to depreciable assets with useful lives of three years or more that were new after December 31, 1953.

One of the methods permitted was the declining-balance method using a rate double the straight-line rate based on full service life. In the declining-balance method, the rate used is applied each year to the depreciated book value (*i.e.*, to the asset account balance minus the depreciation reserve account balance). For example, consider a group of assets having an estimated average service life

of 20 years with zero salvage value. The appropriate straight-line rate is 5 per cent; under the 1954 law, the permissible declining-balance rate is 10 per cent.

Consider a 10 per cent declining-balance rate applied to $50,000 of assets acquired in a given year. If a full year's depreciation is charged for the first year in which any depreciation charge is made, the depreciation charge is $5,000 for the first year, $4,500 for the second, $4,050 for the third, and so on. If the common half-year convention is followed and one-half year's depreciation is charged during the year of acquisition, $2,500 of depreciation is charged for the acquisition year, $4,750 for the first full year thereafter, $4,275 for the following full year, and so on.

A declining-balance rate that is twice the appropriate straight-line rate will write off approximately two-thirds of the depreciable cost during the first half of the average service life of a group of assets. A characteristic of the declining-balance method as applied to groups of assets having zero salvage values is that some book value always remains at any age. With the rates permitted by the 1954 law, from 87 to 90 per cent of the cost of a group of assets will have been written off when the estimated average service life has been reached; this percentage varies slightly with the length of estimated life. In the common case where the longest-lived assets in a group last twice as long as the estimated average life, nearly 99 per cent of the cost will be written off when the final asset of the group is retired.

An alternate optional method permitted by the 1954 law is the sum of the years-digits method. In this method, the digits corresponding to the number of years of estimated life are added together. For example, if the life is 20 years, the sum of the digits from 1 to 20 is 210. The depreciation charge in the first year is 20/210 of the depreciable cost (*i.e.*, of first cost minus estimated salvage value); in the second year, 19/210; in the third year, 18/210; and so on, to 1/210 in the twentieth year.

Another option permitted was any other consistent method that did not result in accumulated allowances at the end of any year greater than the total of the accumulated allowances that would have resulted from the use of the permissible declining-balance rates. This limitation applied only during the first two-thirds of the life. Conceivably, this option might be adopted using two straight-line rates, a higher rate during the first two-thirds of the estimated life and a lower rate thereafter.

16.7 SELECTING A DEPRECIATION ACCOUNTING METHOD UNDER THE 1954 LAW

In the great majority of cases, it will prove advantageous for business enterprises to adopt one of the alternatives to straight-line depreciation permitted for tax purposes under the 1954 law. Such action is in the public interest as well as in the self-interest of the enterprise itself. The liberalization of depreciation tax allowances in 1954 was a distinct step forward—one that was advocated for many years by the author of this section.*

High income taxes constitute a deterrent to many proposed investments in capital goods. Many proposed cost-saving investments in industry that would be economical if there were no income taxes become uneconomical when these tax rates are high. In this way, income taxes constitute a deterrent to technological progress. This deterrent is increased by low allowable depreciation write-offs in the early years of life and is decreased by permission to use a more

* See Chapters 16 to 18 of Grant and Norton, *Depreciation*, for a full statement, first published in 1949, giving reasons favoring tax law changes such as those later adopted in 1954 See Chapter 19 of the 1955 revised printing of *Depreciation* for a discussion of technical aspects of choosing a depreciation method under the 1954 law; this 1955 printing also contains extensive tables applicable to the declining-balance and sum of the years-digits methods.

rapid write-off during the early years. Moreover, the more rapid write-off is consistent with the typical rapid decline in value to the owner of many fixed assets during the early years of their lives; it gives consideration to the fact that many assets are used for stand-by purposes or for other inferior purposes in their final years of life.

If the decision is made to abandon the straight-line method in favor of one of the 1954 optional methods for new assets acquired in 1954 and thereafter, the usual choice will be between the declining-balance method and the sum of the years-digits method. Criteria to govern this choice might properly include the convenience and expense of the depreciation accounting, the differences in rates of write-off under the two methods, and the reasonableness of the respective write-off figures as a guide to various business decisions that are influenced by information from the accounts.

In general, when many assets are included in a single account, the required accounting will be much simpler and less expensive under the declining-balance method than under the sum of the years-digits method. With the former method, one depreciation rate is applied to the entire book value in an account (asset account balance minus depreciation reserve balance) to determine the annual depreciation charge. With the latter method, a different rate must be applied to each year's acquisitions and detailed records showing the exact age of each asset are needed at all times.

The sum of the years-digits method permits a slightly greater write-off during the first half of the estimated service life than is possible with the declining-balance rates allowed by the Internal Revenue Code of 1954. The difference in favor of the sum of the years-digits method is somewhat greater for long-lived assets than for short-lived ones. For example, for assets with a 10-year estimated life, the write-off at the age of 5 years will be 67.23 per cent with the declining-balance method and 72.73 per cent with the sum of the years-digits method. This contrasts with 64.15 per cent and 74.39 per cent, respectively, as the amounts written off after 20 years for assets having a 40-year estimated life. Moreover, some small write-off under the declining-balance method continues until the final unit of a group has been retired, usually some years beyond the estimated average service life. In contrast, the sum of the years-digits method writes off all the depreciable cost (first cost minus estimated salvage value) at the end of the estimated service life and no further write-off is possible when an asset survives beyond that date.

In many instances, a review of the criteria of choice will lead to the conclusion that it is best to use the declining-balance method for groups of assets in such accounts as machinery and furniture and fixtures, particularly if the average service lives of the assets are relatively short and considerable mortality dispersion is expected. In contrast, the sum of the years-digits method will appear to be superior for item accounts such as buildings and structures, particularly where the average service lives are relatively long.

16.8 SEVERITY OF TREASURY TAX PRACTICE

Taxpayers often charge that Treasury officials, in their proper desire to collect all the taxes that are due, are unreasonably severe in administering the tax laws and regulations. Some taxpayers even charge that Treasury officials make a regular practice of anticipating items of revenue and postponing items of expense to the greatest possible extent. Whatever the merits of these charges, there can be little doubt that after 1934, there was an increasing tendency to require that expenses be capitalized and charged off through depreciation deductions whenever the effect of an expenditure extends over more than one year, even though the life expectancy or the productive efficiency of the asset is not increased. The treatment

of roof repairs and of periodically overhauling equipment are examples of this severity of Treasury practice. Gibson discusses this as follows:*

> What underlies the recent trend? Why have Bureau examiners begun to question the deduction of items that were formerly deducted in common practice? The answer may be that they attach too much importance to the term, "Capital Expenditures," disregarding the fact that the expression is not precisely defined, and probably was never intended to be. Examiners are frequently heard to say that such and such items are "capital expenditures by nature" and therefore cannot be expense. Such an assumption bars the very consideration of surrounding circumstances which ought to determine the point. The real question is whether the item is one that can appropriately be a charge against current business. If the answer to that question is "yes," the item is current expense. If "no," then it becomes a capital expenditure (or perhaps a prepaid expense).
>
> *Most* business expenditures, of course, raise no question. Everybody knows that the cost of a new plant is a capital investment. Everybody knows that the pay of the man on the production line is expense. Many kinds of outlay can be classified as readily, but many others cannot. There is a wide borderland between the definite capital expenditures and the definite expenses. In this borderland zone are items not easily tested by indefinite phrases like "increasing the capital value . . . of property." Many others have no connection with items of plant or equipment, but are spent in some intangible undertaking, as in a search for information. Such undertakings are often closely associated with current operation activities carried on by the same personnel. It is literally impossible to know, in connection with the intangible expenditures in a going business, when the books are closed at the end of a year, whether the expenditures will have resulted in the possession of something having a "useful life extending substantially beyond the end of the year."

16.9 "ALLOWED" AND "ALLOWABLE" DEPRECIATION

From 1932 through 1951, the law stated that the basis for future depreciation charges and for determining gain or loss on disposal must be reduced by the deductions since February 28, 1913, "to the extent allowed (but not less than the amount allowable). . . ." The Treasury interpreted this phrase so strictly that the basis had to be reduced by the amount "allowed" or "allowable" each year taken separately. In some cases, the basis over a period of years had to be reduced by an amount greater than the total of either the amount "allowed" or "allowable" taken separately. This situation was corrected to a certain extent by an amendment to the Internal Revenue Code approved on July 14, 1952, effective January 1, 1952, and retroactive to all periods since February 28, 1913, if election was made prior to December 31, 1952. (In 1953, the retroactive deadline was extended to December 31, 1954.) Under this 1952 amendment, the basis must still be reduced by the amount "allowable" each year even if the deduction does not represent a tax saving, but amounts "allowed" that are greater than amounts "allowable" do not reduce the basis except where there has been a tax saving.

Even with the 1952 amendment, a taxpayer may not always recover tax-free his entire investment in an asset whose entire operations have shown a profit, because "allowable" depreciation must still be deducted from the basis in a loss year. This risk of loss is reduced by the privilege of carrying losses back and forward to profit years. But even if losses could be carried back or forward for an unlimited period, a taxpayer would not be completely protected if the amount claimed in a loss year was later held to be less than the amount "allowable" and the year in question was a closed year.

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16.10 TREASURY ATTITUDE TOWARD OBSOLESCENCE

It is only partly true that the Treasury depreciation tax practice after 1934 gave reasonably adequate consideration to the effects of obsolescence. What was called "normal" obsolescence was supposed to receive consideration in figuring the estimated life of the asset. In addition, when it became apparent that the life of an asset would shortly come to an end because of what was termed "extraordinary" obsolescence, the depreciation rate could be increased sufficiently to enable the remaining undepreciated balance to be charged off by the time life came to an end It should be noted particularly that in both types of obsolescence the only effect of obsolescence that was considered was that which ends the life of an asset. Treasury practice after 1934 gave absolutely no consideration to another, and often much more important, effect of obsolescence: the decrease in value *during* life. It must be admitted that Treasury practice in this respect was perfectly consistent with the idea shared with the Treasury by so many accountants and businessmen, that straight-line depreciation, with rates based on full service life is the correct depreciation method. The best way to give real consideration to obsolescence and other factors that cause value to decrease more rapidly in the early part of life would be to use the declining-balance method.

16.11 DEPRECIATION AND PRICE-LEVEL CHANGES

From the depreciation viewpoint, problems are created by price-level changes no matter whether the change is up or down. However, the problem is generally more serious when the change is to a higher level of prices.

When the price level declines, the owner of an asset purchased at the higher price level must expect to have competition from similar machines that represent lower investments, and therefore lower investment charges. Declining price levels thus have a tendency to cause a more rapid decrease in value to the owner than would be the case with a stable price level. Under such circumstances, a conservative management naturally desires to write off the original investment more rapidly, even though nothing has happened that would indicate a shorter service life. Unfortunately, Treasury practices have not generally permitted this more rapid decrease in value to the owner to be recognized for tax purposes through higher depreciation charges. Unlike an increase in the price level, however, a decrease in the price level does not ordinarily cause serious problems in financing replacements.

An increase in the price level causes taxable profits to be greater than economic profits. The amount of cash retained by the company as a result of depreciation charges is not sufficient to replace equipment even when the operations of the company have been profitable before taxes.

During the inflationary period following World War II, many companies attempted to protect themselves in some measure against the effects of the higher replacement cost of equipment by making depreciation charges that were larger than the charges resulting from the usual straight-line method, where depreciation charges are based on the cost of the asset and on the full service life of the asset. These higher depreciation charges were not permitted for tax purposes and have been criticized by many persons as attempts to make profits reported in annual reports seem to be lower than the real profits earned by the company. In the immediate postwar period, a number of these companies attempted to relate these higher depreciation charges directly to the replacement cost of assets that had been installed at lower prices. This practice was opposed by many persons, including the American Institute of Accountants and the Securities and Exchange Commission, and seems to have been replaced in most cases by a method under which charges are based

on cost, but with rates considerably greater than those permitted for tax purposes.

No depreciation method based on original cost can protect the owner of depreciable assets against higher replacement costs, or provide the money for replacements at higher costs, but it is true that the more rapidly the investment is written off (the higher the depreciation rates) the less difficult the depreciation problem becomes under all conditions. What makes the depreciation problem very difficult under the most favorable conditions, and virtually insoluble under inflationary conditions, is the long period of time required for the recovery of investments in plant and equipment. High replacement costs are therefore only one more reason for changing from the straight-line method to a method like the declining-balance method, which is so much more realistic from the economic and financial viewpoints.

There is an important reason why taxpayers may never receive permission to deduct for tax purposes depreciation charges on the higher replacement cost of present assets. Although these taxpayers certainly do have a difficult problem in obtaining funds for replacements, they also have some advantage from the higher replacement costs of their present assets. These higher replacement costs of the present assets should increase the value of the present assets to their owners and make possible higher prices for the products of these present assets. The owners of government savings bonds and other fixed dollar obligations do not have an opportunity to reduce even partially the effects on them of inflation. Proposals to allow depreciation charges on replacement costs to be used for tax purposes would be opposed as a special privilege given to the owners of depreciable assets, and not available to others who also suffer from the effects of inflation.

There can be no doubt that high replacement costs increase greatly the difficulty of the depreciation problem. If the inflation becomes extreme, as was the case in some European countries, it may be necessary to make some adjustments in depreciation practice, such as a revaluation of assets for future depreciation charges. However, it should be remembered that the real purpose of the depreciation charge in the accounts is to record the consumption of existing facilities, and not to provide replacement funds.

17. RETIREMENTS AND REPLACEMENTS

Most of the elements of engineering economy that have been considered in the previous articles of this section appear in some form in a most important problem that has long been a favorite among writers in this general field. The name "machine replacement problem" is the choice of many writers, but does not really cover all the aspects of what can best be discussed as a single broad problem, with many slightly different subdivisions. This discussion will employ the name "retirements and replacements," because in its broadest sense the problem includes all cases where consideration is being given to the substitution of a different method for providing a certain service.

There are often retirements without replacements of depreciable assets. A simple illustration is the decision to purchase an article that has formerly been manufactured. Some of the errors likely to be found in this kind of study have been commented upon in example 19, Art. 14.1.

Even when there is an actual replacement at some time, the retirement and replacement may often not occur at the same time. For example, much productive equipment is installed in periods of great demand without any immediate retirement of existing equipment. Also, there is likely to be considerable retirement of facilities in times of small demand without any immediate replacement. Thus, in many cases, replacement takes place either considerably before or considerably after retirement. This

particular feature of the "replacement" problem is probably the main reason why the "short pay-off" requirement so often mentioned does not really have as much effect as many persons think it does. This requirement will be discussed further in Art. 17.5.

The characteristic that differentiates this particular engineering economy problem is the need to determine the cost of continuing to own and use a present asset. The fact that this determination cannot be avoided is one reason why discussions of this problem appear so frequently in engineering economy discussions. The errors that are so often found in these discussions are the result of failures to understand such things as sunk costs (see example 18, Art. 13.2) and the limitations of accounting information as a basis for business decisions (see example 19, Art. 14.1).

17.1 COMMON ERRORS IN RETIREMENT AND REPLACEMENT STUDIES

Grant discusses these errors as follows:*

Observation of the practice of industrialists in such studies and of the published literature of the subject indicates four errors which it seems are often made in dealing with replacement economy:

1. Considering the excess of present book value over the net realizable value of the old asset as an addition to the investment in the new asset. This error increases the apparent cost associated with the new asset, and thus tends to prevent replacements which are really economical.

2. Calculating depreciation and interest (i.e., capital recovery) on the old asset on the basis of its original cost rather than its present net realizable value. This usually increases the apparent costs associated with the old assets, and thus tends to favor replacements which are really uneconomical.

3. Where indirect costs (burden) are allotted in the cost accounting system in proportion to direct costs (usually in proportion to direct labor cost), assuming without investigation that a reduction of direct expenditures will effect a corresponding saving in indirect expenditures. This error usually makes the apparent saving from proposed replacements greater than the saving which it is actually possible to realize, and thus tends to favor replacements which are really uneconomical.

4. In cases where the proposed new asset provides more capacity than the old asset, comparing unit costs realizable only with full-capacity operation, rather than comparing the actual costs realizable with the expected output. Where such excess of capacity is not likely to be used, this unit cost comparison tends to favor the asset with the surplus capacity, and is therefore favorable to replacements which are really uneconomical.

The first two of these errors cited result from a failure to recognize the true nature of depreciation accounting as a time allotment against future dates of money already spent. The third results from a failure to understand clearly the nature of cost accounting allocations. The fourth is merely an unrealistic use of unit costs.

In spite of the fact that these are obvious errors, formulas containing one or more of them have continued to be copied year after year in textbooks, handbooks and periodicals. The fact that so many unsound formulas are continuing to appear in engineering economy discussions is proof that no one should use any formula unless he understands the derivation of the formula and is sure that the formula may properly be used for the problem being considered.

17.2 THE INVESTMENT COST OF A PRESENT ASSET

Most retirement and replacement studies can best be made by using the annual-cost method explained at length in Art. 4. When all the alterna-

* Grant, *Principles of Engineering Economy*, 3rd ed., pp. 378-379.

tives being considered involve proposed investments, as in the examples of Art. 4, there is generally no difficulty in determining the value that should be used for the investment which must be spread over some future life; this value is simply the estimated cost installed and ready to operate. However, for the reasons given in example 18, Art. 13.2, neither the first cost nor the book value of the present asset provides a rational basis for computing capital recovery cost in a retirement or replacement study. The investment cost of a present asset in a retirement or replacement study should be the realizable value of the asset. This realizable value is the highest of such values as second-hand value, scrap value, or value to the present owner for some other purpose.

17.3 EXAMPLE 20, A REPLACEMENT STUDY

This example is intended to illustrate a number of important elements that may or may not be present in any specific replacement problem. A very important element—the irrelevance of the book value of a present asset—has already been discussed at considerable length in example 18, Art. 13.2.

As stated in example 18, an automatic lathe with a first cost of $4,500 installed is being considered as a replacement for a 10-year-old turret lathe for which the present realizable value is its second-hand value of $1,500, as the company would have no other use for the turret lathe if it were replaced in its present work.

The proposed automatic lathe is so special that its second-hand value would be negligible and it could not be used on any other product of the company. Because of the risk that this product may itself be superseded by another product in a few years, the company is unwilling to invest in this automatic lathe unless the study indicates that the investment will be fully recovered in 5 years. Because the turret lathe is of a type that has a ready second-hand-market, it is estimated that its realizable value at the end of the 5-year study period will be at least $800. This company employs a minimum attractive rate of return of 8 per cent in studies of this sort.

The turret lathe (with its special tooling for this job) has a single-shift capacity on this operation of 4,000 pieces per year, which is approximately the present rate of consumption. The proposed automatic lathe would have a capacity of 10,000 pieces per year on a single-shift basis. There is no present indication that the rate of consumption will increase, but, since this company operates many of its machines on a double-shift basis, it would be a simple matter to increase the production of the turret lathe up to 8,000 pieces per year, if the demand increased even temporarily. Under these circumstances, the additional capacity of the automatic lathe will not be given any consideration in the study, and the machines will be compared on the basis of what it will cost to produce 4,000 pieces per year with each machine.

Because of the several differences between the two machines and the way they are operated in producing 4,000 pieces per year, it is obvious to the officials of this company that the comparison cannot be made on the basis that there will be a saving in factory overhead that is proportional to the saving in direct labor. Therefore, an estimate has been made to determine a reasonable figure for factory overhead with each machine, using estimating methods that are entirely separate from the regular cost-accounting system. It is estimated that for the purposes of this study the annual direct labor costs will be $3,500 for the turret lathe and $1,200 for the automatic lathe; also that all other annual cash disbursements will be $4,200 for the turret lathe and $3,900 for the automatic lathe.

Using these data and the method of example 2, Art. 4.3, the annual costs for the two machines by the accurate compound interest method are:

Turret Lathe

Cap rec. cost	700(0.25046)	=	$ 175
Int. on salv. val.	800(0.08)	=	64
Direct labor cost		=	3,500
Other annual disb.		=	4,200
Total annual cost		=	$7,939

Automatic Lathe

Cap. rec. cost	4,500(0.25046)	=	$1,127
Int. on salv. val.			.....
Direct labor cost		=	1,200
Other annual disb.		=	3,900
Total annual cost		=	$6,227

This study indicates that the replacement should be made, because the prospective savings in operating costs should be sufficient to recover the investment in the automatic lathe during the 5-year study period, plus 8 per cent return on the investment during the recovery, and there should be additional savings of $1,712 per year during the 5-year study period.

By using a cut-and-try method similar to that of example 10, Art. 6.2, it is a simple matter to determine both how *soon* this additional investment would "pay for itself" at 8 per cent interest, and what the "rate of return" would be on the additional investment for a 5-year study period. However, for the reasons given in Arts. 6.4 and 6.5, neither of these items of information is usually important enough to justify the time required to determine it. The amount by which the proposed machine is *better* than the minimum requirement of recovering the additional investment in 5 years plus 8 per cent can just as well be expressed as $1,712 per year as in any other way.

It will be noted that in example 20 the investment charges are much smaller than the annual cash disbursements. There are many cases where either this or the reverse situation is true. In such cases, it is obviously important to give full consideration to the accuracy of the data in the portion which has the greater effect on the final values. On the other hand, in this particular case there is enough margin so that a very considerable inaccuracy in the estimates of annual disbursements would hardly reverse the indication that the replacement should be made.

17.4 THE ECONOMIC LIFE CONCEPT

The phrase "economic life" occurs frequently in discussions of retirement and replacement theory, but the exact meaning is not always clear. Machines certainly have economic lives in the sense that their economic lives come to an end when they are replaceable for economic reasons, but these economic lives are certainly not attributes of the machines as distinguished from their surroundings and use. Grant discusses this idea as follows:*

> The notion that an asset has an inherent economic life determinable in advance is decidedly misleading. However, if enough elements of the replacement economy situation were immune from change, "economic life" would then have a definite and useful meaning. If each new asset could be counted on to repeat the cost history of its predecessor asset, having the same first cost, the same salvage value at each age, and the same annual receipts and disbursements as its predecessor for each year of life, there would be one particular life that would be economically superior to all others If receipts, other than salvage value, were independent of age, the economic life would be the one that resulted in minimum equivalent uniform annual cost in the long run. This economic life would depend not only on the pattern of cost history but also on the assumed interest rate or minimum attractive return.

The information given in Arts. 11 and 15 on amount of utilization and on appraisals will be helpful in understanding why the economic life of an asset comes to an end primarily because of external causes rather than things inherent in the asset itself. In addition, even in cases where it might be reasonable to make estimates for the future on the basis of

* Grant, *Principles of Engineering Economy,* 3rd ed., p. 516.

replacing assets with presumably identical assets for use in service that seems to be identical with the previous service, the fact of mortality dispersion in the lives of seemingly identical assets makes it impossible to state that any specific asset should be retired when it reaches an age equal to the average life of the group. Further information about this point may be found in Art. 16.5.

Those desiring an extensive discussion of the economic life concept should refer to treatises that develop the concept from its basic principles.* Here we can say only that when one is seeking to determine whether an asset should be retired (i.e., whether it has reached the end of its economic life), the age of the asset and the relationship of that age to average realized lives of similar assets are both completely irrelevant. In making a retirement study to determine whether a specific asset should be retired, the age of the asset means nothing. The real question at issue is whether the prospective future cost with the present asset will be more or less than with the most economical available substitute asset.

17.5 LENGTH OF PAY-OFF PERIOD

Whenever equivalent uniform annual costs are determined by spreading an investment over a prospective life, it is, of course, necessary to set a period (usually called the pay-off period) during which the investment is expected to be recovered. When calculating the capital recovery cost for a proposed investment, the usual procedure is to assume zero salvage value at the end of the pay-off period, which is frequently much shorter than the prospective service life.

There is no general agreement on what is meant by the pay-off period. Sometimes the method used requires that there be a complete recovery of the investment in the study period plus a minimum attractive rate of return on the investment during the study period. In other cases, the only requirement is that the investment be recovered in the study period, with no return on investment during the study period. In some discussions of the problem, there even seems to be confused reasoning in the interpretation of this element of the study.

The writer believes that in most cases it is better to view the pay-off period and the minimum attractive rate of return as two separate components of the problem, as was done in examples 1, 2, 3, and 20 However, satisfactory results often seem to be attained by using a study period that is relatively short and omitting the rate-of-return charge, the idea being that if the study indicates that the investment will be recovered in the rather short period, the chances are good enough that the asset will be useful for an additional period that is long enough so that there will be both a recovery of the investment and also the necessary return on the investment during recovery. Probably the best argument against this practice is that it really does not save much time or effort in making the study, and the results are certainly not as easy to interpret as when the pay-off period and the minimum attractive rate of return are included separately.

It is often reasonable to concentrate attention on the early years of the lives of assets, in which case it is also often reasonable to estimate as a salvage value the prospective value to the owner at the end of the study period. Grant discusses this as follows:*

> Where it seems likely that such factors as improved alternatives, changes in service requirements, and increasing operation and maintenance costs with age will combine to give a rapid decline in value to the owner during the early years of life, this prospect should be considered in an economy study. Another reason for giving particular attention to

* See George Terborgh, *Dynamic Equipment Policy* (New York: McGraw-Hill Book Company, Inc., 1949). See also Chapter 20 of Grant, *Principles of Engineering Economy*, 3rd ed.

* Grant, *Principles of Engineering Economy*, 3rd ed., pp. 198-199.

the early years of life is the difficulty of making reliable forecasts for the more distant future. When it is proposed to acquire new assets, it may be evident that there is a prospective market in the immediate future for the product or service that they will make possible. However, the continuation of this market for a long period may be uncertain. Often it may seem reasonable to make estimates for, say, 5 years, but not for 20 years, when the purchase of machinery with an estimated service life of 20 years is contemplated. One needs only to recall the happenings of the past 20 years to realize the uncertainties involved in forecasting the next 20. It is common for prospective purchasers of plant and machinery to feel that if they do not succeed in recovering the major part of their investment in the early years of life, they are likely never to recover the full investment.

For these reasons it is often appropriate for engineering economy studies to use study periods much shorter than the full expected service life. Obviously the appropriate study period must depend on the type of assets that it is proposed to acquire and on all the surrounding circumstances. However, many circumstances exist where it is reasonable to follow one of the two following suggestions:

1. Assume the study period to be one-half the estimated life and make estimates for this period. Require that three-fourths of the first cost (plus, of course, the minimum attractive rate of annual return) be recovered during this period.

2. Where estimates for as long as one-half the life do not seem to be justified, assume the study period to be one-fourth the estimated life and make estimates for this period. Require that one-half the first cost (plus minimum attractive return) be recovered during this period.

17.6 THE MAPI FORMULA

Two volumes prepared under the auspices of the Machinery and Allied Products Institute (MAPI), a trade association, deal particularly with the economic analysis of the problem of replacing industrial assets. The first of these, *Dynamic Equipment Policy*,* by George Terborgh, its Research Director, presents the Institute's theoretical analysis of the problem. The second, *MAPI Replacement Manual*,† gives brief directions for making replacement economy studies using a formula referred to as the MAPI formula. In these two volumes, the asset considered for replacement is called the *defender;* the proposed replacement asset is called the *challenger.*

The basic MAPI formula is given at the top of page 167.

To judge whether a proposed replacement will pay, the MAPI method compares the "adverse minimum" figures for challenger and defender. The challenger's adverse minimum is obtained from a diagram that gives an approximate solution of the MAPI formula. The defender's adverse minimum is the sum of (1) the next-year defender inferiority to the challenger, (2) the prospective loss in defender salvage value during the next year, and (3) one year's interest on the defender's present salvage value. The next-year defender inferiority is the sum of the challenger's next-year income advantage and operating cost advantage.

The following is believed to be a reasonably accurate brief statement of certain assumptions underlying the MAPI formula:

1. The need for the present product or service will continue forever.

2. The present challenger is the first of an endless succession of challengers, a new one being available each year.

3. Each new challenger will have the same initial cost as the present challenger, the same economic service life, and the same salvage value at the end of that life.

4. The operating inferiority of each year's challenger to the next year's challenger will be a constant figure.

5. The salvage value of the present challenger and all future challengers will

* New York: McGraw-Hill Book Company, Inc., 1949.

† Machinery & Allied Products Institute, *MAPI Replacement Manual* (Chicago: Machinery & Allied Products Institute, 1950).

Challenger's Adverse Minimum =

$$\frac{in\left[ci + rs\frac{1}{(1+i)^n}\right] - s(i+r)\left[1 - \frac{1}{(1+i)^n}\right]}{in + \frac{1}{(1+i)^n} - 1}$$

where c = first cost of the challenger
n = estimated service life of the challenger
s = estimated salvage value at the end of that life
i = the interest rate, expressed as a decimal
r = a symbol for $\frac{2.30259}{n}$ (log c − log s)

decrease at a constant rate throughout life.

The foregoing reference to the MAPI method is included here to suggest this method as a topic for study by persons dealing with economic analyses of replacements. A detailed explanation of the theoretical and practical aspects of this method of analysis would require extensive space. It is recommended here that analysts should not use the MAPI formula uncritically without an attempt to understand its theoretical basis as developed in *Dynamic Equipment Policy.* Unless an analyst understands the underlying assumptions of the MAPI method, he is not in a position to judge whether expected departures from these assumptions are of importance in each particular case.*

18. INCOME TAXES IN ENGINEERING ECONOMY

Income tax rates on both corporate and personal income are certain to be high in this country for many years to come. This fact makes it necessary to give consideration to prospective income taxes when making most types of engineering economy studies. There are so many peculiarities in the application of the income tax laws and regulations that it is not possible in this discussion to do more than call attention to some of the more important points that should be considered when engineering economy studies are being made. Further information may be obtained from publications specializing in the various aspects of this important problem.*

It will be remembered that engineering economy studies are based on a consideration of anticipated future receipts and disbursements. As prospective income taxes are merely one more disbursement, all that is really needed is to add them to the other prospective disbursements. However, as is true for a number of other kinds of disbursements, there is often considerable difficulty in determining just how to include them in the study.

18.1 GRADUATED INCOME TAXES REQUIRE INCREMENT COST VIEWPOINT

In this country, most individual income taxes, both federal and state, are graduated. The higher the taxpayer's taxable income, the higher his tax rate on the highest increment. Because of this, when an individual makes an economy study, he should use the increment cost viewpoint when estimating the effect on prospective income taxes of the proposal being studied.

As certain types of income, such as the interest on state and municipal

* For a brief critique of certain aspects of the MAPI method, see Grant, *Principles of Engineering Economy,* 3rd ed., Chapter 20.

* See Grant, *Principles of Engineering Economy,* 3rd ed., Chapter 17, for a more extended discussion of this problem.

bonds, are exempt from federal income taxes, a wealthy individual often finds it desirable to choose tax-exempt securities with low interest rates instead of investments that show promise of quite high returns before income taxes. This tax exemption enables states and municipalities to borrow at low interest rates, but is socially undesirable otherwise because the return from the safer investments has been forced down to the point where the lower-income groups no longer can afford to invest in them, while the wealthier persons, who should undertake the riskier ventures, find it undesirable to do so because of the income tax situation.

18.2 EFFECTIVE TAX RATES FOR USE BY CORPORATIONS

In this country, corporate net income is first taxed to the corporation and then any distributions to the shareholders are again taxed to the individuals receiving such dividends. Wealthy shareholders often find it desirable to leave in the corporation most of the earnings after corporate income taxes, so as to avoid high individual income taxes that would otherwise result from a distribution in the form of dividends. This practice is discouraged by Section 102 of the Internal Revenue Code, which imposes a "surtax on corporations improperly accumulating surplus."

It is evident from what has just been said that what might be called the "effective tax rate" on the earnings of a corporation depends upon the proportion of the earnings that is distributed as dividends and also upon the incremental individual tax rates of the various owners. This poses a difficult problem, which is discussed by Grant as follows:*

> As a practical matter, prospective income taxes paid by the stockholders are likely to be disregarded in some corporations and considered in others, somewhat as follows:
>
> 1. In corporations with many stockholders, in which most policy decisions are made by executives whose personal stock ownership is relatively small, the tendency is to consider only the corporate income tax. Most large corporations fall into this class. Where there are many stockholders whose personal incomes are unknown to the management, it is hardly practicable to consider stockholders' income taxes. Moreover, the performance of hired managers is judged by the profit showing on the corporate books.
> 2. In corporations with few stockholders, with those stockholders taking an active part in policy decisions, individual income taxes are much more apt to be considered. In such corporations, Section 102 often forces distribution of most of current earnings as dividends. Stockholders taking an active part in management are likely to be very conscious of the income taxes they pay on these dividends. Although corporations in this class are generally smaller, they are more numerous.

* Grant, *Principles of Engineering Economy*, 3rd ed., p. 403.

18.3 SPECIAL SITUATIONS

Because taxable income is often quite different from economic income, there are many special situations that require special treatment in engineering economy studies. For example, certain income may be exempt from income taxes; this has already been illustrated in the case of the exemption from federal income taxes of the interest on state and municipal bonds.

Some types of income may be taxed at lower rates; an illustration is the treatment of certain gains from the disposal of capital assets and of depreciable assets used in business.

Certain deductions from taxable income may be quite different from economic and accounting deductions. For example, certain losses from the disposal of capital assets are not deductible taxwise, while there are special tax deductions for such things as depletion.

Certain deductions from taxable income may be spread out over a much longer future period than a businessman may consider to be proper or even safe.

The tax treatment of depreciation is a good example.

Sometimes tax practice requires the capitalization of an expenditure that the businessman considers to be a current expense. This has been illustrated in Article 16.8, as part of the discussion of the severity of Treasury tax practice.

18.4 INCOME TAXES MAY LIMIT LOSSES

Sometimes a taxpayer may be able to force the government to share with him any loss that may develop from a risky undertaking. For example, consider a proposal to make a certain expenditure in a year in which there is a reasonable certainty that there will be taxable income from other sources at least as great as this expenditure. Provided this risky expenditure is fully deductible for tax purposes in the year in which the expenditure is made, it is clear that even if the venture in question is a total loss, the taxpayer will lose only that part of the expenditure which exceeds the amount that would be paid out in taxes if the expenditure were not made.

As an illustration, if the effective tax rate is 70 per cent, the complete loss of an expenditure of $10,000, which is fully deductible from taxable income from other sources, would result in a net loss of only $3,000 to the taxpayer, the other $7,000 being a loss to the government, because of the resulting reduction in income taxes. It is because of this that businessmen are likely not to be so careful to keep deductible expenditures to a minimum when tax rates are high and when there is reasonable assurance of some taxable profits after all such expenditures. Thus high tax rates sometimes result in economic waste.

This opportunity for the limitation of a loss from a risky venture is, of course, much more valuable to large, well-established concerns with many other profitable ventures than to small, newly organized concerns, most of whose eggs may be in this one risky basket. However, this is only one of the many instances of the ways in which high income tax rates are relatively more burdensome and more dangerous for small and growing businesses than for large and well-established businesses.

18.5 INTEREST ON BORROWED CAPITAL IS A DEDUCTION FOR TAX PURPOSES

Under high income tax rates on business profits, borrowed capital has a great advantage tax-wise over equity capital because the interest paid out on borrowed capital is a deduction that reduces income taxes, whereas there is no such deduction for any part of the return on equity capital. There is an old saying that doing business on borrowed money makes good business better and bad business worse. The fact that interest payments may be deducted when calculating taxable income certainly accentuates this condition.

Individual businessmen must, of course, consider this feature of the tax laws when making decisions, but from the viewpoint of the public a large industrial debt structure is very dangerous.

18.6 INCOME TAXATION AND TECHNOLOGICAL PROGRESS

It was stated at the very beginning of this section that a high standard of living depends upon a high degree of mechanization. Mechanization requires capital. Income taxes remove capital that could otherwise be used for investments in capital goods. Thus income taxes may retard technological progress. The higher the effective income tax rate, the less attractive it is to make investments in plant and equipment. Anything that interferes with technological progress is an obstacle to improvements in the standard of living and may also be an obstacle to real national defense.

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SECTION 4

Manpower Management and Employment Relations

Dale Yoder

1. MANPOWER MANAGEMENT AND EMPLOYMENT RELATIONS

In a very real and practical sense, all management is manpower management. True, other resources—power, physical materials and facilities, and financial provisions and arrangements—must certainly be managed, but they are all managed and manipulated by people. The production manager actually manages the men who carry on production processes. The sales manager may never "manage" a single sale; he directs men who plan and effect sales. Every foreman, supervisor, and executive manages men and thus practices manpower management.

Recognition of the importance of manpower management has resulted in two significant developments in recent years. It has encouraged alert employers to become interested in programs designed to make all managers better manpower managers. And it has stimulated specialists in manpower management and employment relations to strive for professional status. As a result, personnel managers and industrial relations directors (and their assistants) are now accorded staff status in many business and public institutions. Evidence of the grow-

ing recognition of manpower management is provided by the increasing volume of research and by the special graduate, technical and professional training available in many universities.

1.1 NATURE OF MANPOWER MANAGEMENT

Societies live and advance through the development, application, and conservation of their resources, including manpower resources. By continued trial and error—and more recently by study, experimentation, and research—they learn how to make the most of these resources, how to develop them more fully, how to apply them more effectively, and how to conserve them and avoid waste. These general procedures are readily evident in the development of steam, water, and atomic power and in the use of the basic mineral and land resources from which such power is derived. Water power has been harnessed —and in the process water wheels and turbines have been developed, dams and reservoirs have been built, and water power has been transformed into electric power. Continued development of physical resources has led to steam-turbine and diesel-electric locomotives, jet and turbojet aircraft engines, and experimental atomic motors.

1.1.1 Human resources. Similar improvement in the development and application of human resources is somewhat less obvious, perhaps because human resources are the most complex as well as the primary resources of society. Laws and principles that describe the properties of coal, timber, and petroleum seem relatively uncomplicated when compared with the principles that govern human behavior.

1.1.2 Self-imposed management. Moreover, human resources are—at least in modern societies—the final determiners of the social objectives for which they are employed. Societies exist for these human resources. Their ideas, desires, needs, whims, prejudices, and ideals dictate the goals of their societies. Yet they are its most elementary resource.

Thus in modern societies, human resources must, in order to survive, prescribe and enforce their own efficient utilization. They must design and maintain procedures for the most effective development and application of human personalities in combination with other resources. This efficient utilization of human resources and their conservation, the prevention of waste, is the major responsibility of modern manpower management.

1.1.3 Voluntary employment. The process of developing, allocating, and applying human resources takes place through voluntary employment, in which human beings on their own initiative join with other resources in producing goods and services. Allocation of manpower to various industries and occupations is largely accomplished through a "labor-marketing" function that results in employment. Similarly, much of the training and shaping of personalities, their application to productive processes, efficient utilization of their potentialities, and their careful conservation is accomplished through employment.

1.1.4 Necessity for manpower management. Manpower must be managed in employment if efficient use is to be made of other resources. Hence the manpower-management function—the planning, direction, and control of human resources in employment—must be performed in all societies. It is essential in every type of employment—for every occupation and industry, for every type of employed manpower. Manpower management takes place in government as well as in private employment, under socialism and communism, in small business and in large. The development, allocation, utilization, and conservation of human resources *through their employment* is a continuing, inevitable process in modern societies. Manpower management plans and directs this process.

1.1.5 Responsibility for manpower management. Manpower management represents such a wide range of activities

and is of such importance that responsibility for it is shared by many agencies. Individual managements (note the plural, to distinguish those in charge of single firms from the inclusive *function* of *management*) are probably the most easily recognized. They hire manpower, give employees various types of training (thus influencing the process of personality development), compensate employees, assign jobs, arrange shifts, transfers, and promotions, provide various services, and perform many related tasks. In a sense, the entire management of an individual firm is engaged in manpower management, since all department heads, supervisors, and foremen manage men.

1.1.5.1 Union responsibilities. Currently in our society, officers of labor organizations are also given important responsibilities in manpower management. They may, under so-called "closed-shop" arrangements select the employees who are to be assigned to various employers. They perform a similar function through their control of hiring halls for longshoremen. Through their direction of apprenticeship programs, they exert a powerful influence in training employees. They represent employees in collective bargaining, thus affecting the determination of rates of wages, hours of work, and other employment conditions. They may also provide various services to employees, such as counseling, financial benefits, and insurance.

1.1.5.2 Government in manpower management. Government agencies—federal state, and local—also have an important role in manpower management. Public employment offices aid in allocating manpower to various industries, areas, and occupations. Other government agencies exert a significant control over conditions of work: specifying minimum wages and maximum hours, enforcing safety regulations, limiting employment of women and children, preventing discriminatory hiring practices, and requiring observance of specified "rules of the game" in collective bargaining. They seek to settle disputes, to mediate differences and conflicts, and to maintain industrial peace.

1.1.5.3 Individual employee responsibilities. In a democratic society, individual employees also have a responsibility in manpower management. They decide for themselves where—in what localities and in what industries—they will seek employment. They control their personal development—decide whether to continue their formal education, to enter an apprenticeship program, to seek a transfer from one job or department to another, to join a union, or to start a business and thus become self-employed. Their decisions directly affect their own allocation, utilization, and contribution.

1.1.5.4 Specialized employment relations staff. Within individual firms and government agencies, specialized staffs provide professional and technical advice on relationships among the principal participants in employment. The staff is headed by an industrial relations director, or a personnel manager, or some similarly titled person. He—and the specialized assistants who may be included on his staff—are set apart from the operating line. This arrangement is by no means novel in modern industry and government. The specialists are protected from the pressure of day-to-day operation so that they can keep abreast of developments in their professional and technical fields. Their value depends in large measure on their awareness of changes, innovations, experiment, and research. It is their responsibility to maintain their specialized competence and to make their services and counsel available to line operators at all levels.*

Staff status makes them available to aid all who practice day-to-day manpower management. Their position is similar to that of other staff divisions, such as the legal or medical.

1.1.6 Specialized terminology. Many of the terms with which manpower management is described have been carelessly used. Consequently, its function is often misunderstood. In popular usage, for example, the terms "personnel man-

* This point of view has been clearly explained by Lawrence A. Appley in "Management The Simple Way," *Personnel*, Vol. 19, No. 4, January 1943, 4-6.

agement," "industrial relations," "labor relations," and many others are used interchangeably, as though they had the same meaning. In one study, it was found that some 72 titles were held by the more than 700 "manpower managers" who reported.* Even the other members of the management team frequently make little distinction between the personnel manager and the labor relations director or the industrial relations director.

A distinction should be made, however, since several jobs—rather than a single job—exist in this area. The "Industrial Relations Glossary" † defines two of these terms as follows:

> *Personnel management:* The selection, allocation, utilization, development, and control of employees and the improvement of working conditions in order to secure maximum productive efficiency; primary emphasis on individuals rather than on groups.
>
> *Industrial relations:* The relations of persons and groups growing out of employment in the production and distribution of goods and the provision of services.

The term "labor relations" is properly applied to the negotiation and administration of union agreements—that is, to group relationships. The terms "industrial relations" and "employment relations" encompass both individual employer-employee relationships and employer-union, collective-bargaining relationships. As Heneman and Turnbull have said:‡

> Differences in definition represent a serious handicap in achieving one of the requirements of a profession, a common terminology. There are, however, several reasons for believing that the trend is toward using "industrial relations" as the basic term. First, almost all of the university training and research organizations established since World War II use 'industrial relations' in their titles. Second, surveys of job titles and organization structures of employment departments in business show increased usage of "industrial relations" as the broader term. Third, this trend is reflected in the professional literature.
>
> For these reasons, and to insure uniformity of presentation, the present volume utilizes "industrial relations" as the broadest term, with "personnel administration" (dealings with individual employees) and labor relations (dealing with groups of employees) as sub-headings.

1.1.7 Specialization in staff jobs. These distinctions are set forth in more detail in the three job descriptions in Figs. 4.1, 4.2, and 4.3. In the situations in which all three positions are included, the chief of the manpower management staff is designated the Vice-President in Charge of Industrial Relations or the Industrial Relations Director. He has two coordinate assistants, one, the general personnel manager, in charge of "individual" employee relationships, and the other, the labor relations director, in charge of group relationships, especially collective bargaining.

In larger organizations, the personnel or manpower management staff may have several specialized functions. Figure 4.4 identifies and briefly describes some 16 specialties, professional and technical, in the employment relations division.

1.1.8 Staff and line in manpower management. In actual practice, line operators play a major role in manpower management. They manage men—all the time and in every aspect of their employment relationships. Specialists in employment relations—including industrial relations directors, personnel managers, and their assistants—serve as staff to the operating managers. The staff service thus provided may be either minimal or extensive. The manpower staff may consist of a single personnel manager or industrial relations director; this is the usual situation in smaller

* Dale Yoder and P. N. Wilson "Trends in Personnel Ratios and Salaries," *Personnel*, Vol. 29, No. 1, July 1952, 1-7.

† University of Minnesota Industrial Relations Center, *Bulletin 6*, 1948.

‡ Herbert G. Heneman, Jr. and John G. Turnbull, *Personnel Administration and Labor Relations* (New York: Prentice-Hall, Inc. 1952), pp. 3-4.

FIG. 4.1 JOB DESCRIPTION, INDUSTRIAL RELATIONS DIRECTOR*

Title—Industrial Relations Director

Alternate Titles—Director of Labor-Management Relations, Vice-President in charge of Industrial Relations, Personnel Administrator, Personnel Manager

Promotion to—Chief Executive of Firm, General Manager

Promotion from—Personnel Director, occasionally Director of Personnel Research, Wage and Salary Administrator, Labor Relations Director, Line Department Heads

Duties—This is the top position in the field of industrial and labor relations or personnel work. In industry the individual holding this position works under the general administrative direction of the chief executive of the organization. Through continuous consultation with line officers and other staff officers he appraises, formulates, recommends, and interprets all manpower management policies; reviews and appraises the application of these policies; is responsible for continued evaluation of all personnel policies; organizes, staffs, trains and supervises all divisions of the Industrial Relations Department.

He recommends policy for the planning, coordination, and control of: recruitment, selection and placement processes, educational and training programs, wage and salary administration, incentive and bonus plans, economic security programs, personnel research projects, communication between management and personnel, maintenance of appropriate personnel records, safety and health programs, collective bargaining, labor relations, and grievance procedure. He cooperates with the legal counsel in maintaining compliance with federal and state laws and regulations; maintains contacts with other industrial relations executives, in order to evaluate their experience. He formulates personnel policy interpretations for public release, assumes responsibility for the general direction and coordination of employment activities, and cooperates with schools and colleges as a part of recruitment and research programs.

Responsibility for Policy—All personnel policy recommendations by members of the staff are sent to the Industrial Relations Director who in turn makes recommendations to top management.

Initiative Required—A high degree of initiative is necessary in regard to organizational work and policy making for the entire field of industrial relations.

Responsibility for Work of Others—Supervises the work of the Personnel Director, Director of Personnel Research, Medical Director, Wage and Salary Administrator, and Labor Relations Director.

Training—Much of the training for this position must generally be obtained on the job.

Working Hours—Hours are frequently long and irregular.

Qualifications for Employment—

Sex: A man is required in practically all instances.

Education: Educational qualifications for this position generally include a college degree plus specialized education at the graduate level with emphasis on industrial relations, public administration, labor legislation, personnel research, office management, production management, collective bargaining, economics, psychology, statistical methods, engineering, time and motion study, and adult vocational education.

Experience: Several years of experience in public contacts and general personnel administration are necessary

Personnel Qualities: Superior ability to organize and to administer, ability to secure acceptance of the program by members of his department as well as by other executives and employees, good judgment, resourcefulness, and tact; interest in helping others to be satisfied and successful in their work.

Mental Ability: Equivalent to a superior college graduate.

Special Knowledge: Familiarity with current industrial relations problems and policies, labor markets, governmental regulations, and organizational aspects of the business.

* From Philip H. Kriedt and Margaret Bentson, "Jobs in Industrial Relations," University of Minnesota Industrial Relations Center, *Bulletin 3*, 1947, 25.

FIG. 4.2 JOB DESCRIPTION, PERSONNEL DIRECTOR*

Title—Personnel Director

Alternate Title—Personnel Manager

Promotion to—Director of Industrial Relations

Promotion from—Employment Manager, Training Director, Safety Director, Recreational Director, Employee Services Director, Employee Counseling Director

Duties—The holder of this position is responsible for direct relations with individual employees and for the establishment of proper working relationships within the personnel department and with other departments. He directs and supervises activities that involve workers as individuals such as welfare, recreation, safety, and counseling.

He supervises employee counseling, reporting to top management on trends observed and correctable grievances discovered; conducts interviews and conferences relative to work, employee morale, and employee welfare; assigns, trains, supervises, and reviews the work of staff members responsible to him; and may lay out and direct general plans for administrative processes involved in executing a system of promotion and transfer and other similar rules and regulations. He advises and counsels in connection with health, child labor, social security, workmen's compensation, and veterans' rehabilitation. Maintains contacts with personnel officers in other companies and with governmental, management, and professional organizations concerned with personnel activities; cooperates with the Public Relations Director in the release of data to employees or to the public.

Responsibility for Policy—General personnel policy recommendations concerning relations between management and individual workers are an important responsibility of this position.

Initiative Required—A high degree of initiative is necessary in planning and directing the work of a large number of assistants.

Responsibility for Work of Others—Supervises the Employment Manager, Training Director, Safety Director, Recreation Director, Employee Services Director, and Employee Counseling Director.

Training—Much of the training for this position must be obtained on the job.

Working Hours—Hours are frequently long and irregular.

Qualifications for Employment—

Sex: Either.

Education: A minimum of four years of college including courses in: industrial and personnel psychology, industrial relations, vocational and occupational psychology, social psychology, labor problems and labor economics, occupational studies and job analysis, statistical methods, labor and social legislation, production management, and industrial engineering.

Experience: Several years of paid, full-time, recent employment in personnel work and related types of service, including individual diagnosis, vocational and educational guidance, employment management, and labor relations are desirable.

Personal Qualities: Ability to maintain industrial harmony, interest in employees as individuals, observant and sincere; ability to organize and administer.

Mental Ability: Equivalent to a college graduate.

Special Knowledge: Understanding of the principles of industrial relations; knowledge of individual differences in abilities, aptitudes, interests, and personality traits; familiarity with local labor markets and wage rates.

* From Kriedt and Bentson, "Jobs in Industrial Relations," 37.

FIG. 4.3 JOB DESCRIPTION, LABOR RELATIONS DIRECTOR*

Title—Labor Relations Director

Alternate Title—Labor Relations Counselor

Promotion to—Director of Industrial Relations

Promotion from—Assistant Labor Relations Director, Union Business Agent

Duties—The Labor Relations Director advises and counsels management concerning relations with organizations of employees; provides counsel on legislation and regulations affecting labor relations; negotiates and assists in the administration of labor agreements; assists in handling grievances, in appraising employee morale, in advising all departments of the meaning and interpretation of collective bargaining agreements and of current developments in negotiation and bargaining; informs management of current and prospective labor market conditions; represents management in conciliation and arbitration procedures; assists in preparation of employee handbooks and manuals; assists in handling disciplinary cases; may maintain records and statistics on employee grievances and their settlement; may work in conjunction with similar representatives of other firms on a bargaining committee for the industry or locality.

Responsibility for Policy—Responsible directly to the Director of Industrial Relations for formulation of policy recommendations regarding labor relations.

Initiative Required—A high degree of initiative is needed in negotiation, conciliation, arbitration procedures, and in advising departments of labor agreements and negotiations.

Responsibility for Work of Others—Supervises assistants and secretaries.

Training—Sufficient on-job training to gain familiarity with the unions having agreements with the firm, with union contracts, and company policies and practices.

Working Hours—Work outside regular hours is frequently required while union contracts are being negotiated.

Qualifications for Employment—

Sex: A man is usually required.

Education: A legal degree with supplementary courses in industrial relations is desirable. Important courses are: labor and industrial legislation, office management, principles of economics, industrial engineering, labor management, public administration, personnel psychology, and statistics.

Experience: Several years of experience in working with organized labor are necessary

Personal Qualities: Ability to make investigations and studies, to analyze trends and forecast developments in collective bargaining, to act as liaison between management and organized labor, and to be tactful, resourceful, and firm.

Mental Ability: Equivalent to a college graduate.

Special Knowledge: A thorough knowledge and understanding of federal, state, and local legislation on collective bargaining, hours of work, minimum wages, child labor, picketing, and boycotts; similar knowledge of the regulations and procedures established by the principal federal and state agencies which deal with labor standards, employment, public contracts, and collective bargaining; knowledge of common contract clauses and of negotiating techniques.

* From Kriedt and Bentson, "Jobs in Industrial Relations," 28.

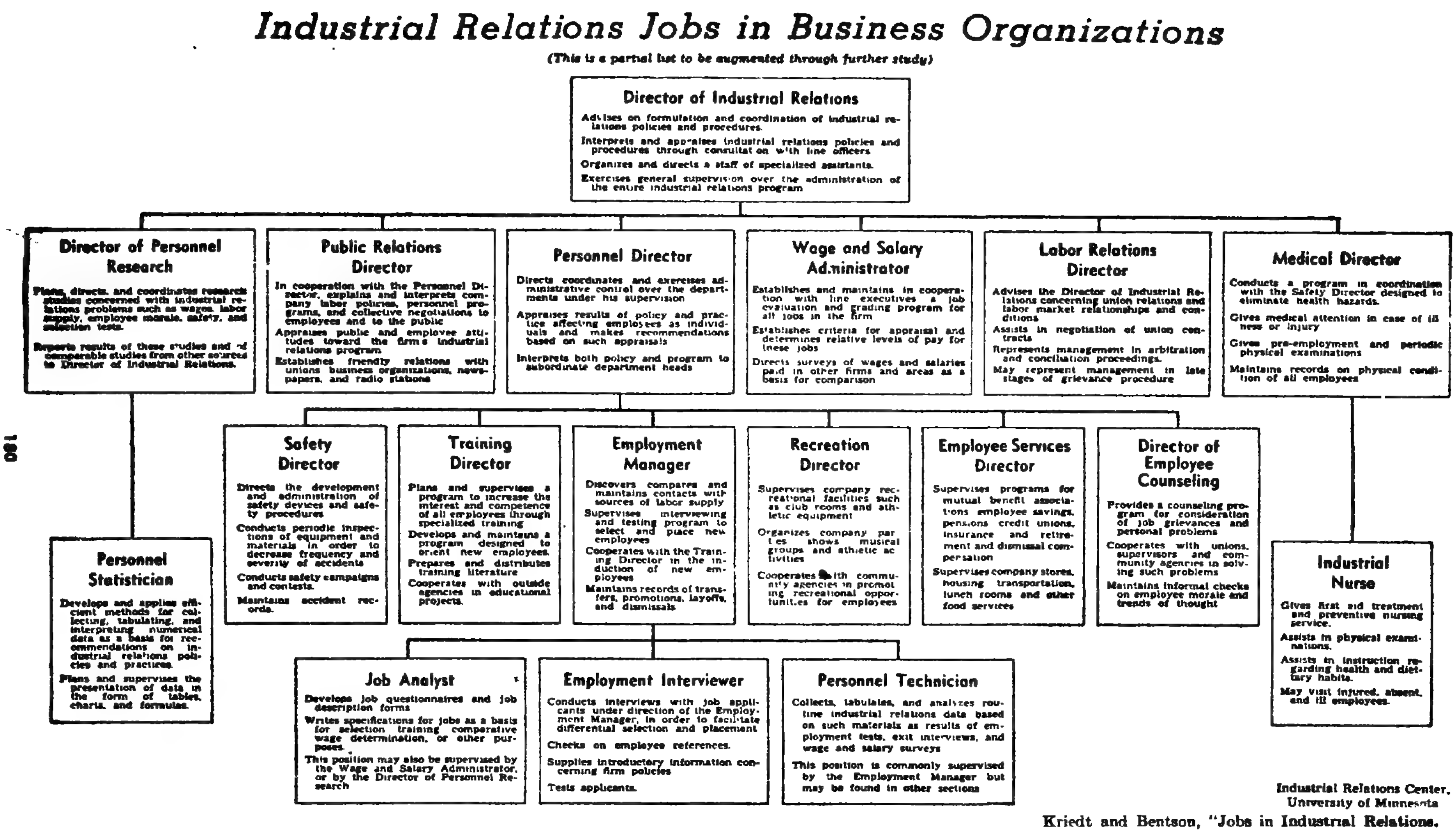

FIG. 4.4 INDUSTRIAL RELATIONS JOBS IN BUSINESS ORGANIZATIONS.

TABLE 4.1 PERSONNEL RATIOS, 1948-1952, BY NUMBER OF EMPLOYEES *

Number of employees	Personnel ratios				
	1948	*1949*	*1950*	*1951*	*1952*
1-499	1.06	1.07	1.29	1.04	1.13
500-999	0.91	0.75	0.83	0.92	0.78
1,000-1,499	0.59	0.62	0.67	0.71	0.94
1,500-1,999			0.52	0.68	0.73
2,000-2,499			0.75	0.63	0.74
2,500-2,999			0.76	0.70	0.63
3,000 & over			0.70	0.74	0.57
All	0.81	0.78	0.87	0.75	0.61

* Reproduced by permission from Yoder and Wilson, "Trends in Personnel Ratios and Salaries," 8.

firms. In larger business or governmental organizations, however, the staff may include a wide range of specialists.

1.1.8.1 Use of Consultants. Small firms usually secure expert assistance on specialized problems by employing consultants on a time-to-time basis. For example, the personnel manager may bring in outside assistance in designing a new test battery for selection, or in installing or revising the job-evaluation program, or in establishing a new personnel-rating procedure. The local personnel manager, in such cases, is a practitioner somewhat like the family doctor. He does not claim special competence in unusual conditions, but he is able to recognize them and knows when to call on experts who are especially prepared to deal with them.

1.1.9 Personnel ratios. What is the optimum size of the personnel staff? How many persons should be employed to provide specialized personnel services? The answers to these questions depend, of course, on the range of personnel activities and services to be carried on. Certain bench marks are available, however. For a large number of firms and government agencies, the over-all personnel ratio averages about 0.80. This means that the total number of specialized staff personnel in manpower management averages 0.80 per hundred employees served.

In general, the personnel ratio is higher in smaller firms. Apparently a minimum staff forces this ratio upward, and the staff does not expand at the same rate as employment. This relationship is made clear by Table 4.1, which reports the findings in an analysis of returns in a series of annual surveys.

1.1.9.1 Industry differences. Personnel ratios vary widely from one industry to another. The 1952 survey (see Tables 4.1 and 4.2) indicates a range from 0.28 (in transporation) to 1.11 (in banking and finance.) Differences in these ratios over a four-year period are shown in Table 4.2.

1.1.9.2 Titles and size of firm. Some relationship is apparent between the size of firms (in terms of numbers of employees) and the titles given to those in charge of the manpower maangement staff. The "Industrial Relations Director" appears more frequently in large firms than in small. The smaller organizations are more likely to have a "Personnel Director" or a "Personnel Manager." In both large and small firms, an increasing tendency to make the top manpower manager a vice-president is clearly evident.

1.1.9.3 Salaries and size of firm. Salaries also reflect the size of firm. In 1952, the chief of the personnel staff in firms having fewer than 500 employees received an average salary of $6,410. For firms of 500 to 1,000 employees, the average was $7,533; for 1,000 to 1,500, $8,255; for 1,500 to 2,000, $9,466; for those over 3,000, $13,844.

TABLE 4.2 PERSONNEL RATIOS, 1949-1952, BY INDUSTRY CLASSIFICATION *

Industry classification	Personnel ratios			
	1949	*1950*	*1951*	*1952*
Manufacturing	0.74	0.83	0.85	0.63
Trade	1.03	0.88	0.39	0.62
Construction	—	0.69	—	0.69
Banking and Finance	1.36	1.47	1.34	1.11
Transportation	1.28	0.80	0.40	0.28
Other Public Utilities	0.66	0.75	0.48	0.59
Government	1.02	0.33	0.49	—
Miscellaneous	0.82	1.00	0.72	0.72
All	0.78	0.87	0.75	0.61

* Reproduced by permission from Yoder and Wilson, "Trends in Personnel Ratios and Salaries," 8.

1.1.9.4 Salaries and titles. Salaries also reflected distinctions in title. Those reporting the title of personnel manager or director averaged $7,993, while those who held the title of industrial relations director averaged $12,238. Vice-presidents averaged $22,467. The remainder, a composite group having approximately 30 different titles, averaged $8,814.*

1.2 MAJOR ACTIVITIES IN MANPOWER MANAGEMENT

The general function of manpower management is to insure the efficient provision, development, and utilization of manpower resources in employment. Looked at from the negative point of view, it is to prevent long-term waste of manpower resources in employment relationships. To this end, the day-to-day practices of manpower management must first of all provide manpower of the desired quality in whatever quantities are required. It must recruit, select, and place manpower. As a basis for recruitment and selection, management must provide a schedule of manpower requirements. Such a schedule, often described as a *staffing schedule* or *manning table,* is based on detailed job analyses and a study of the interrelationship of jobs.

Since much of the manpower thus provided must be given special training to fit it to the jobs to be performed, training is also an important function. After training has been completed, manpower must be transferred, promoted, compensated, and otherwise guided and directed to insure its efficient and enthusiastic participation in the ongoing activities of the business or agency. Continued attention must be given to communication and motivation. Frequent checks on morale and a continuing program of personnel rating are other responsibilities.

Employees sometimes prefer to deal with employers through their own organizations. Then collective bargaining —the negotiation and administration of collective agreements—becomes a major function of manpower management. Various benefits and services may be provided for employees—health, insurance, hospitalization, investment advice, recreational guidance, and many others. In some cases these services are established on a unilateral basis by action of the employer. In others, they are agreed upon in contracts with unions.

In all these relationships, appropriate records must be maintained. Also, a continuing program of research helps to

* These data are more fully detailed in Yoder and Wilson, "Trends in Personnel Ratios and Salaries."

provide acceptable answers to significant questions arising in the day-to-day or longer-term practice of manpower management.

1.2.1 Specialized functions. Among the major functions that stand out from even such a panoramic survey of the field, the following may be readily noted:

1. Formulation of manpower policy.
2. Planning of manpower programs.
3. Continuous review and appraisal of manpower policy and programs.
4. Job analysis.
5. Organizational planning.
6. Recruitment.
7. Selection.
8. Placement and orientation.
9. Training.
10. Collective bargaining.
11. Wage and salary administration.
12. Personnel rating.
13. Maintenance of effective in-plant communication.
14. Maintenance of motivation and morale.
15. Employment stabilization.
16. Direction of employee benefits and services.
17. Maintenance of records and reports.
18. Industrial relations research.

The relative significance of these functions varies from industry to industry and from plant to plant. But employment relations programs in most organizations include most of them. Table 4.3 provides a more detailed outline of these functions and activities.

TABLE **4.3** AN OUTLINE OF PERSONNEL ACTIVITIES *

I. Organization for Personnel Administration
   1. Basic responsibilities of executive, staff, line and personnel organizations with respect to employee relations
   2. Committee organization on policy matters
   3. Staff personnel assistance to line executives
   4. Administration by personnel organization of special services to line organization, such as employment, training, etc.
   5. Promotion and coordination of personnel policies, plans, and activities—headquarters staffs, committees, conferences, liaison procedures, and written instructions on personnel matters
   6. Auditing of effectiveness of personnel policies and practices

II. Administration and Supervision
   1. Duties, responsibilities, and authority of executive and supervisory personnel in relation to company operations
   2. Channels of communication upward and downward—both for supervisors and individuals—with respect to job information, individual problems, and grievances
   3. Opportunities for participation in planning, decisions, or suggestions on job matters either as supervisors or individual workers through "multiple management" plans or "consultative supervision"
   4. Supervisory skills, including job instruction, handling employee relations, job methods, conference leadership

III. Employment
   1. Forecast of requirements for personnel
   2. Hiring policies and standards
   3. Job descriptions, qualifications required, and rates of pay
   4. Recruitment
   5. Interviewing and testing
   6. Pre-employment medical exam
   7. Reference investigation
   8. Induction
   9. Placement and follow-up in relation to performance, ability, interests, special qualifications or handicaps, and job opportunities
   10. Employee records and statistics
   11. Labor market studies
   12. Exit interviews

IV. Training and Employee Development
   1. Induction and orientation program, including relationship of employee's work to that of other

(continued)

* Reproduced by permission from H. H. Carey, "An Outline of Personnel Activities," *Personnel*, Vol. 23, No. 6, May 1947, 384-387.

workers, departments, and branches
2. Job training—shop and office
3. Supervisory training—presupervisory, on-the-job, and conference groups
4. Executive and supervisory development program
5. Out-of-hour courses
6. Educational and vocational guidance
7. Employee evaluation
8. Cooperation with schools and colleges

V. Wage and Salary Administration
1. Job evaluation and grading
2. Establishments of job rates and rate ranges
3. Incentive plans—time studies and standards
4. Rate reviews and adjustments, including employee performance and merit ratings
5. Wage and salary rates and earnings surveys—within company and outside market
6. Wage and salary controls—within company and outside
7. Pay for time not worked—vacations, holidays, disability or personal absence, jury duty, shutdowns, etc.
8. Special allowances or bonuses

VI. Force Adjustment
1. Work load and requirements for personnel
2. Promotions, demotions, and transfers
3. Voluntary quits, layoffs, and discharges
4. Employee inventory and rating plans
5. Channels of progression
6. Seniority and disciplinary matters
7. Progression training and rotational assignments
8. Standards and selection procedures for advancement
9. Centralized placement and control

VII. Relationships Between Employees and Management
1. Statement of employee relations policies
2. Relations with employees as individuals
3. Employee organizations
4. Collective bargaining
5. Grievance procedure
6. Arbitration
7. Employee-management committees

VIII. Hours and Working Conditions
1. Work schedules
2. Physical working environment and facilities
3. Vacations and holidays
4. Rest periods
5. Music at work
6. Suggestion system

IX. Health and Safety
1. First-aid and hospital facilities
2. Physical examinations—preemployment, occupational, and periodic health
3. Occupational placement and control of assignments of vocationally handicapped or partially disabled
4. Safety rules and regulations
5. Employee consultation with company doctors
6. Emergency and first-aid organization
7. Safety and health committees and training programs
8. Visiting nurse service
9. Accident investigations
10. Research and control of hazards
11. Safety and health handbooks
12. Periodic inspection of plant and equipment
13. Fire drills
14. Publicity
15. Safety equipment and clothing

X. Benefits and Economic Security Matters
1. Accident compensation
2. Sickness benefits
3. Protection of service through leaves of absence
4. Employment stabilization
5. Plans for pensions, annuities, life insurance, savings, stock purchase, hospitalization, surgery, etc.
6. Expense allowances—living, transfer, transportation
7. Special assistance in emergencies and unusual cases of need
8. Termination allowances

XI. Services to Employees
1. Cafeterias and restaurants
2. Credit union facilities
3. Sales to employees of company or other products

4. Transportation and housing
5. Recreational and educational facilities and programs
6. Payroll deduction plans
7. Legal matters and notary public
8. Employee counseling and assistance on personal problems

XII. Communication with Employees
1. Employee publications and periodicals
2. Informational booklets
3. Personnel policy statements
4. Bulletin board notices
5. Annual reports
6. Special meetings

XIII. Research and Development
1. Studies on turnover, absenteeism, etc.
2. Evaluation of company personnel programs and activities
3. Supervisory and employee attitude and morale surveys
4. Outside company personnel practices and industry trends
5. Labor legislation—state and federal
6. Employee census
7. Controlled experimentation on working conditions, training, supervisory techniques, etc.

XIV. Relations with Local Business and Community Organizations
1. Community news—employment, financial, educational, and welfare organizations
2. Plant visits and "open house
3. Trade, management, and professional associations in personnel field
4. Outside company contacts
5. State and federal agencies
6. News releases and information about the personnel aspects of company operations

1.3 MANPOWER POLICY AND PROGRAM

Professional manpower managers must develop appropriate labor and manpower policies and must design and perfect programs for policy implementation. Policies are a statement of the organization's manpower goals. They describe what the employer—or the combination of employer, union, and individual employees—seeks to accomplish in the allocation, utilization, and conservation of manpower resources. They include both general objectives and the specific goals in each of the major functions outlined in the preceding section—selection, compensation, etc.

Programs are courses of action to be taken at all levels of the organization in carrying out established policies. They include recruitment programs, for example, or programs designed to implement policies in selecting, promoting, training, or retiring. They represent a considered series of actions, planned to accomplish precisely the objectives described in the established manpower policies.

1.3.1 Staff responsibility for policy and program. Employment relations staff members have important responsibilities in connection with both policy and programs. Although major policies should be formally adopted and established by top-line executives or by collective bargaining, it is the responsibility of staff specialists to counsel and advise on such policies and to provide expert evaluations of suggested policy. Moreover, the staff has a responsibility to see that proposals for change in policy or for new policies come to the attention of policy "determiners." They have further responsibility to see that policy is communicated and interpreted throughout the entire organization. To that end, they propose means of communication and interpretation. They may be given specific responsibility for preparing and circulating standard policy statements and for the continued codification and integration of policy.

1.3.2 Secret policy. What about those aspects of labor policy that are regarded as confidential or secret? What about policies that propose to limit employees to members of a single race or to avoid employment of older persons or members of certain nationalities? In general, current practice seeks to avoid policies that cannot be disclosed and openly supported and justified. So-called "unwritten policies"—regarded as traditional and binding although they have not

been put into spoken or written words—are generally avoided.

1.3.3 Staff review and appraisal. A major responsibility of manpower staff members is to maintain a continuing review and appraisal of labor policy and related personnel programs. The adequacy and propriety of existing policy must be considered as well as suggestions for new policy and for changes in policy. Suggestions for change may come from supervisors and administrators, from negotiators, from individual employees, or from developments in the field and policy changes initiated in other concerns or localities. It is the staff's responsibility to suggest changes that will keep manpower policy abreast of the time.

Also, the manpower staff must constantly examine existing programs to see whether they are effective in accomplishing their purposes. At regular intervals, staff members must provide an over-all audit of the entire personnel or industrial relations program. In essence, such an audit—usually made each year—checks the entire program against established policy. The basic question is: Does the program effectively accomplish what policy sets as established goals?

1.4 ORGANIZATION OF THE EMPLOYMENT RELATIONS DEPARTMENT

As has been noted, in smaller organizations the entire industrial relations staff may consist of a single "personnel manager" or "industrial relations director." In larger organizations, staff members may be numerous and may have highly specialized responsibilities. What organization is appropriate within the manpower management staff?

1.4.1 Scalar status. As is true of any staff department or division, the position of the staff unit in the organization as a whole is a primary consideration. Since the staff is created to counsel and serve the line, the chief of the staff must have sufficient "scalar status" to make his advice effective. In other words, the staff must have access to the line at a high level if its influence is to be effective throughout the entire line organization. That is why many staff chiefs hold the title of vice-president. In any case, the representative of the employment relations staff should sit in on top-management executive sessions, and he should participate actively in the discussions that precede decision-making at this level.

1.4.2 Internal organization. Figure 4.4 suggests a possible organization within the industrial relations department. Note, however, that it presents a composite outline of the specialties found in many firms and agencies. Aside from the primary distinction between the personnel manager and the labor relations director, the specializations most commonly found are safety (see Art. 2, Section 11) and health (See Art. 11, Section 12). (including all medical and nursing programs), wage and salary administration, training, employment (recruitment and selection), and research. Figure 4.5 illustrates the organization of one large department.

1.4.3 Specialized assignments. R. K. Dailey has provided an excellent summary of the organizational specialization of a large industrial relations department.* He describes the major divisions as follows:

"The objective of the (whole) employee relations department—to develop and maintain good relations between employees of all levels and thus obtain high productivity per individual worker—is of course the objective of all departments in any company. . . .

"The *Medical Division's* objective is the continued good health and well-being of every employee. . . .

"It is the *Safety Division's* responsibility to promote safe working conditions and practices at all times and to administer and handle all matters pertaining to safety. . . .

* Excerpts from "The Organization and Administration of Industrial Relations Departments in Large Firms," *Proceedings, Seventh Annual Industrial Relations Conference*, University of Minnesota Industrial Relations Center, 1949, 19-28.

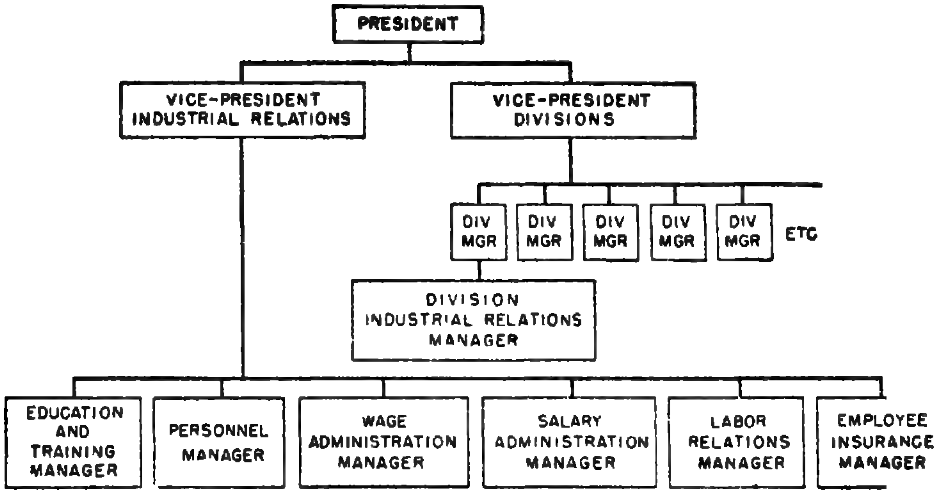

FIG. **4.5** ORGANIZATION OF THE INDUSTRIAL RELATIONS DEPARTMENT.

"The *Training Division* has the important job of helping to develop and train employees, supervisors and executives—and the particularly important job of developing potential executives. . . .

"The *Employee Benefits, Employee Services*, or *Welfare Division*, as it may be called, has as its objective the administration of all matters pertaining to the employee benefits program and the maintenance of personnel records. . . .

"The functions of a *Research Division* in the employee relations organization may vary considerably between companies; however, the research function is an important one. . . . In many companies, the research function is combined with the function of Salary and Wage Administration. . . .

"The *Personnel Division* is principally concerned with employment and placement of qualified personnel."

1.4.4 Multi-plant organization. In many large organizations, a central employment relations staff provides counsel for top management, and individual plants and divisions have their own manpower management staff members. Lines of authority and responsibility in such arrangements are governed by the general organization of the firm or agency. If the local plants have complete autonomy, their industrial relations staff members are similarly autonomous. More commonly, matters of general policy are established in the central offices, and local adjustments and amendments are provided by those in charge of each plant. In such arrangements, local staff members are responsible to the central staff for continued evaluation of whatever aspects of the whole program the central office prescribes. In addition, they are responsible to local executives for additional programs provided in the individual plant.

1.5 COSTS OF MANPOWER MANAGEMENT

Evidence of the cost of providing professional employment relations services is limited and inconclusive. Over-all costs—calculated per employee or on some other appropriate basis—are not readily comparable, because of differences in the number of functions performed in various organizations. Some programs are far more extensive and inclusive than others.

As one approach to this important question, studies have been made of the costs of individual "personnel" or "labor relations" or "industrial relations" functions. But even these comparisons are difficult, since the degree of responsibility that manpower managers have for these specific programs varies greatly. For example, in some organizations the

TABLE **4.4** EMPLOYMENT-RELATIONS EXPENSES PER EMPLOYEE, BY FUNCTION AND INDUSTRY GROUP[a]

Function	Number of units	All industries Dollars	All industries Per cent	Manufacturing Dollars	Manufacturing Per cent	Trade Dollars	Trade Per cent	Banking, finance, and insurance Dollars	Banking, finance, and insurance Per cent	Transportation Dollars	Transportation Per cent	Other public utilities Dollars	Other public utilities Per cent	Others Dollars	Others Per cent
Services and benefits	145	9.21	18.9	8.27	17.0	24.33	38.7	11.15	15.8	1.99	7.4	13.81	20.1	11.38	16.9
Medical, health, and safety	139	8.45	17.4	9.68	19.9	4.34	6.9	4.88	6.9	3.89	14.5	14.12	20.6	13.77	20.5
Training	134	4.56	9.4	5.46	11.2	5.67	9.0	7.24	10.2	1.27	4.7	4.37	6.4	1.94	2.9
Labor relations	129	3.89	8.0	2.58	5.3	2.75	4.4	.70	1.0	5.80	21.6	8.74	12.7	12.57	18.7
Administrative planning	151	2.41	5.0	2.01	4.1	3.08	4.9	5.22	7.4	2.18	8.1	4.61	6.7	2.81	4.2
Communications	121	2.12	4.4	2.15	4.4	2.45	3.4	2.45	3.5	2.46	9.2	.60	.9	1.46	2.2
Records and reports	144	2.06	4.2	1.94	4.0	2.62	4.1	5.14	7.3	1.30	4.8	2.70	3.9	3.20	4.7
Wage and salary administration	141	1.97	4.0	2.02	4.2	2.05	3.2	4.04	5.7	1.01	3.8	2.51	3.6	3.36	5.0
Recruitment	149	1.90	3.9	1.52	3.1	4.46	7.1	7.36	10.4	.47	1.7	3.69	5.4	1.78	2.6
Selection	148	1.63	3.4	1.37	2.8	1.97	3.1	2.80	4.0	1.17	4.3	4.30	6.3	1.79	2.7
Induction and placement	146	1.48	3.1	1.80	3.7	1.03	1.6	2.17	3.1	.54	2.0	1.49	2.2	1.48	2.2
Promotion, transfer, and termination	134	1.42	2.9	1.60	3.3	2.56	4.1	1.79	2.5	.30	1.1	1.08	1.6	1.30	1.9
Policy formulation	146	1.21	2.5	1.23	2.5	.99	1.6	3.80	5.4	.78	2.9	1.05	1.5	2.34	3.5
Organization planning	112	1.12	2.3	.96	2.0	.80	1.3	2.11	3.0	1.00	3.7	1.03	1.5	4.58	6.8
Job analysis	118	.98	2.0	1.09	2.2	.69	1.1	2.15	3.0	.54	2.0	1.42	2.1	.58	.9
Research	108	.86	1.8	.68	1.4	.68	1.1	2.05	2.9	1.09	4.1	1.14	1.7	2.02	3.0
Personnel rating	111	.79	1.6	.82	1.7	1.27	2.0	1.87	2.6	.42	1.6	.77	1.1	.31	.5
Public relations	91	.67	1.4	.89	1.8	.27	0.4	.70	1.0	.39	1.5	.36	.5	.23	.3
Auditing the program	87	.49	1.0	.46	0.9	.68	1.1	2.77	3.9	.27	1.0	.46	.7	.12	.2
Other	29	1.37	2.8	2.19	4.5	.23	0.4	.27	0.4	.00	0.0	.36	.5	.20	.3
All	155	48.59	100	48.72	100	62.92	100	70.66	100	26.87	100	68.61	100	67.22	100

[a] From Dale Yoder and Lenore N. Wilson, "Employment Relations Functions and Budgets," *Personnel*, Vol. 29, No. 3, November 1952, 225.

entire administration of the pension and retirement program is vested in the industrial relations division. In others, however, this responsibility is shared with the payroll or accounting department.

A report released through the American Management Association* describes the experience of twelve large concerns with an average employment of 29,000 and a total employment of 344,000. Total industrial relations staff costs amounted to $50.72 per employee and ranged from $24.24 to $63.75. The average monthly salary of industrial relations staff members was $411.

Average payroll costs per employee for ten major activities of these staff divisions were summarized as follows:

General administration	$8 23
Employment activities	5.86
Training activities	3.91
Wage and salary administration	5.37
Safety	5.80
Medical services	4.53
Employee benefits activities	4.59
Employee services activities	3.30
Labor relations activities	2.80
Personnel records	4.75

These were total expenses; most of them were charged to the field (department, division, and plant), rather than to the central staff.

A more inclusive survey of these costs was undertaken by the University of Minnesota Industrial Relations Center in 1952. Average costs were found to be approximately $50 per employee. Important differences among several industry classifications were noted. Costs of some 20 major functions are summarized in Table 4.4.

2. COLLECTIVE BARGAINING

Modern manpower management is not initiated and maintained entirely by the employer, although employers have long played an important role in manpower management. In the Middle Ages, when employment relationships were largely those of master and serf, the employer was patently the dominant figure. Later, in the days of early merchant and trader capitalism, much of this dominance was retained by employers. When national economic philosophies were built about the notion of *laissez faire,* and when all intervention by government was regarded as undesirable, the overwhelming responsibility of the employer for manpower mobilization, allocation, and utilization was apparent to all.

As theories of political democracy achieved wider acceptance, however, the tendency to place major responsibility for manpower management in the hands of employers lessened. National and local governmental agencies began to intervene in regulating employment relationships. At the same time, public opinion came to support—whereas it had in the past prohibited and deplored—the organization of employees and the encouragement of group bargaining with employers. In this new climate of public opinion, permanent organizations of employees—unions—demanded and received increasing responsibility for determining many of the conditions of employment. Government agencies and unions thus came to share the authority and responsibility formerly held by employers. Manpower management was forced to recognize many employer-group relationships, in addition to those relationships between an employer and individual employees that had predominated in the past.

These employer-union aspects of manpower management currently exert a powerful influence on all conditions of employment. In all industrialized nations, collective bargaining—the none too satisfactory designation given to the most obvious phase of these relationships—is a major function in manpower management.

2.1 UNION INFLUENCE IN POLICY AND PROGRAMS

Union participation in manpower management extends into both policy determination and program-plan-

* *Management News,* Vol. 22, No. 10, October 31, 1949, 3.

ning and administration. Through collective bargaining (and, to some extent, through political pressure) unions seek to influence on the one hand, basic policy —the stated intentions or objectives in employment relationships—and, on the other, the development and day-to-day administration of programs designed to implement these policies. They have developed a strong and pervading determination to increase and maintain their power in all these situations. Unions have thus, in a sense, become ends in and of themselves.

Originally, unions were a means of advancing the economic interests of employees. Early unions sought to secure higher incomes and to protest against unemployment and the displacement of employees by machines. As union influence expanded, these objectives remained in the forefront. But unions have also sought to give status and recognition to employees, to prevent arbitrary action by employers, and thus to provide added security in employment.

2.1.1 Range of bilateral action. In current practice, joint action of employers and unions in manpower management extends into a wide range of managerial functions. Unions participate in many phases of employment relationships. Perhaps the best evidence is provided by an analysis of the content of collective agreements or labor contracts. A classification of the usual clauses, such as that in Fig. 4.6, clearly indicates the range of this joint activity.

FIG. **4.6** CHECK-LIST OF CLAUSES IN COLLECTIVE AGREEMENTS*

Formal provisions

Preamble and purposes of the agreement
Life of the agreement
Signatures of the parties
Copies of labor agreement
Amendments
Change of employer

Union recognition

Exclusive bargaining agency
Bargaining agent for members only
Bargaining unit
Labor Management Relations (Taft-Hartley) Act

Union security

Closed shop
Union shop
Preferential shop
Maintenance of membership
Agency shop
Work on non-union materials
Union label or shop card
Wearing of union insignia
Labor Management Relations (Taft-Hartley) Act

Union representation

Union representatives

Grievance procedure

Grievances
Labor Management Relations (Taft-Hartley) Act

Strikes and lockouts

Strikes and lockouts
Labor Management Relations (Taft-Hartley) Act

Union activities and rights

Union business activities
Union notices
Pledge of no coercion, interference, or intimidation
Union obligations
Company encouragement of union membership ("harmony clause")
Inclusion of union constitution and by-laws
Unionization of competitors
Collection of union dues
Labor Management Relations (Taft-Hartley) Act

Management rights

Management prerogatives
Company rules and regulations
Bulletin boards
Contracting work out
Patents or inventions
Employment standards

Wages

Agreement increases
Operating or individual increases
Wage rate schedule
Job rating, classification, and evaluation
Incentive wages
Reopening of wages

* From "Union Contracts and Collective Bargaining Practice," *Labor Equipment*, Vol. 4 (New York: Prentice-Hall, Inc.), pp. 500, 501, 502.

Reporting pay
Call-in pay
Waiting time
Travel allowances
Portal-to-portal pay
Special clothing or tools
Reimbursements to company
Payroll deductions
Night-shift differentials
Payment of wages
Lost-time allowances
Transportation or relocation allowances
Bonuses and profit-sharing
Guaranteed employment
Annual wage
Guaranteed work clause
Wage reductions prohibited
Retroactive back pay

Working time and leave

Regular hours
Shift hours
Meal periods
Rest or relief periods
Clean-up period
Make-up time
Company meetings
State and federal regulations
Election Day voting privileges
Overtime and premium time
Holidays
Lateness
Absence
Vacations
Leaves of absence
Sick leave
Military leave

Employment relationships

Seniority
Promotions and demotions
Lay-off
Discharge
Resignations

Working conditions

Governmental regulations
Company responsibilities
First-aid facilities
Sanitary facilities
Eating facilities
Safety and fire-protection equipment
Safety organization
Workmen's compensation
Physical examinations

Insurance and benefit plans

Insurance and benefit plans
Prior or existing benefits
Labor Management Relations (Taft-Hartley) Act

Special employees

Apprenticeship
Foremen
Labor Management Relations (Taft-Hartley) Act

2.2 CONTRACT NEGOTIATION AND ADMINISTRATION

Collective bargaining consists of two principal phases. One is concerned with initiating and negotiating the collective agreements or labor contracts that specify the jointly determined conditions of employment. The other is contract administration—the day-to-day interpretation and application of the principles outlined in negotiated agreements.

Contract negotiation is essentially an exchange of proposals and counter-proposals. It is customary to think of the union as the major "proposer" and the employer as the "opposer." But in many relationships this is by no means necessarily true. It is true, however, that many employers have tended to wait and see what the union wants and then to decide how far to go in acceding to these demands. Such employers adopt a negative or passive role in the negotiatory stage of collective bargaining, allowing the union to take the offensive or active part. In many other situations, unions have appeared as the active party because they have given publicity to their demands, whereas the employers have made their objectives known only after the union demands have been publicized.

In recent years, however, a sharp tendency for employers to assert themselves and to take a more active and positive role in negotiation has become apparent. Most expert opinion has approved this change, holding that only if both parties enter negotiations with carefully considered demands and outspoken notice of the changes they desire can the process result in efficient conciliation of differences and a workable agreement.

2.2.1 Preparation for negotiation. If the actual process of negotiation—which usually takes place in a relatively short period—is to result in a satisfactory working arrangement, both parties must usually spend a great deal of time in preparation. They must discover what they wish to obtain in the negotiating sessions. Within unions, such a process means a more or less formal canvassing of the interested membership. For employers, it means a similar examination of the opinions of executives, supervisors, and individual employees. In both cases, what are considered desirable goals in negotiation may be complicated if not contradictory. Little agreement may be found on what either of the parties should seek. Divergent and opposed interests must be integrated and compromised.

2.2.1.1 Sources of information. In order to decide on appropriate proposals, both the employer and the union may have to examine the record They will find it helpful to consider the experience of the past with respect to:

1. Grievances. What have been the major sources or subjects? What present contract provisions have been found inappropriate or inadequate?

2. Violations. What sections of existing agreements have been subject to most frequent violations? Why?

3. Arbitration awards. How has the existing agreement been interpreted and modified by arbitrators' decisions during the term of the contract? Should these changes be incorporated in the new contract, or should existing clauses be modified to prevent such interpretation?

4. Amendments. Has it been necessary to amend the present agreement during its term? If so, should these changes be incorporated in the new agreements?

5. Unsettled issues. What points of dispute are pending? How should they be resolved in the new agreement?

6. Industry and area developments. What changes have appeared in the agreements negotiated by other firms in the industry or area that may be appropriate in the new contract?

2.2.1.2 Supporting facts and arguments. In deciding what proposals are to be made, both parties must consider how each proposal can be justified. They must discover, organize, and be prepared to present supporting information. Since for some issues the process of developing the case may be extensive and time-consuming, preparations must be begun many months before actual negotiations are to start. Extensive research may be essential.

The Employee Relations Division of the National Association of Manufacturers has provided the following summary of preparatory steps:*

"A. Before entering negotiations, management should be fully and accurately informed on:

1. All pertinent information about the wage rates involved, as related to job descriptions, from such sources as:
   - Competitor companies in the industry
   - Companies in the community
   - Wage surveys
   - Bureau of Labor Statistics bulletins and periodicals
   - National Industrial Conference Board publications
   - Trade associations, employers' associations, etc.
2. Employees' average hourly earnings and average weekly earnings.
3. Figures on the cost of living, both nationally and for the particular locality.
4. A clear, factual picture of the problems peculiar to the company, supported where possible by charts and tables so that the information may be readily transmitted to the other party.
5. Facts that will show the effect that employee and union demands will have on the company's ability to carry on its business and continue to make employment possible.

* From *Management Guide for Collective Bargaining* (New York: National Association of Manufacturers, Employee Relations Division, 1943), pp. 9-11.

6. Contractural relations of companies in the same industry and in the community.

8. The rights of management under existing laws and statutes relating to labor relations.

9. The laws, decrees, and regulations, whether Federal, State, or local, applicable to employment relations.

"B. If the company has not had any previous negotiating experience, it is advisable for management to consult with competent counsel who is thoroughly informed in the field of labor relations, before entering upon negotiations.

"C. It is important for management to think through its own position in connection with the fundamental factors that enter into the employer-employee relationship, so that it may adhere firmly and intelligently to such principles as it believes are basic to the operations of its business.

"D. It must have clearly in mind, prior to negotiations, the extent to which management's prerogatives and rights must be retained.

"E. Prior to and during negotiations, management should thoroughly discuss with its supervisors those matters of union-management relationship in the plant which have been particularly troublesome to supervisors, foremen, and the like. This discussion will give management a first-hand grasp of the actual problems that supervisors must face in their daily relations with the rank and file.

"F. Management should be fully informed of the labor relations policies being administered throughout the plant."

Another illustration of the steps that may be taken in preparing for negotiation is the wage-data worksheet illustrated in Fig. 4.7.

2.2.2 Selection of negotiators. The negotiating representatives of each of the parties must be carefully selected. The following outline suggests current practice:*

No 'standard practice' in the designation of employer or union negotiators can be described. Actual negotiations may be carried on by a single representative or by a committee. Negotiating committees may include only two or three members, or they may be much larger. If large committees represent each of the parties, and if committee members participate freely in discussions, the rate of progress may be retarded. On the other hand, such committees have many advantages. They broaden the educational aspect of negotiation. More representatives of each of the parties get to learn the other side's viewpoint at first hand. Agreements thus hammered out should have fewer 'bugs' in them. Moreover, negotiators should have much less difficulty in securing ratification by their principals

"In what is perhaps the most widely satisfactory procedure, a large committee is created for planning negotiations, a small subgroup is designated to carry on the actual negotiations, and a single spokesman is named as chairman of the latter group For the employer, the large planning committee may include representatives of each division, including several first-line supervisors. From this group a subcommittee of three, five, or seven, headed by the labor relations director, may be designated as bargaining representatives. For the union, the business agent, local president, or international representative may be chairman of the bargaining group When the two groups meet, these chairmen act alternately as principal spokesmen, calling on other members on specific questions or whenever these members indicate a desire to be heard.

"There is much to commend broad participation in negotiations. Agreements must be ratified by both parties. Particularly in the case of the union, such ratification may be more easily secured if a number of members have worked on the agreement and are in a position to recommend it. Further, those who have been present in negotiations are better

* From Dale Yoder, *Personnel Principles and Policies* (New York: Prentice-Hall, Inc., 1952), pp. 318-319.

FIG. 4.7 WORKSHEET FOR THE COMPILATION OF WAGE DATA TO BE USED IN NEGOTIATION*

Year:	'38	'39	'40	'41	'42	'43	'44	'45	'46	'47
Number of employees: Male										
Number of employees: Female										
Minimum wage: Male										
Minimum wage: Female										
Av. Hrs. Worked per Wk.										
A. H. W. in Industry										
A. H. W. in all Mfg.										
†Av. Hr. Earnings										
†A. H. E. for Industry										
†A. H. E. for all Mfg.										
†Av. Weekly Earnings										
†A. W. E. for Industry										
†A. W. E for all Mfg.										
Community Cost of Living Index										
National Cost of Living Index										
‡Man hrs. per unit of product										
‡Labor cost per unit of product										
‡Units of product mfg. per employee per month										
Earnings of Company										
% paid to employees										
% paid to stockholders										
% reinvested in company										
Cost to Company of.										
Vacation Plan										
Paid Holidays, if any										
Shift Bonus, if any										
Rest periods, if any										
Other Fringe Benefits										
Cost to Company of.										
Group Insurance Plan										
Cafeteria										
Medical and Health Services										
Credit Union										
Safety Program										
Other Welfare Programs										
Total Cost										
% of yearly payroll										
Cost per employee										

* From "Preparing to Negotiate," *Management Memo No. 2* (New York: National Association of Manufacturers, Employee Relations Division, March 1947), p. 13.
† Prepare figures with and without overtime.
‡ If obtainable, similar data for Industry would make comparison more meaningful.

1. For quick comprehension, reduce to chart form.
2. Add complete job rate schedule as an appendix.
3. Wage data for employees outside the specific bargaining unit may also be compiled.

able to interpret and apply the resulting contract. They know what the parties agreed to and can thus supplement the limited statement included in the formal agreement.

"*Prestige and authority.* It is desirable that each side be represented in negotiations by persons having authority to make some commitments. Bargaining is slowed if each minor concession and adjustment tentatively accepted must be referred to a higher authority for approval. For this reason, it is sometimes suggested that the employer should be represented by the president or other chief executive, while the union spokesman should be an international officer or someone else who is fully authorized to make final and binding commitments. Sometimes the authority and prestige of the bargainers is depended on to make whatever agreement is reached acceptable to all those thus represented.

"However, such arrangements provide only a superficial solution to a very complicated problem. The agreement worked out in negotiations should be practical and usable and truly satisfactory to those whose daily efforts are to be shaped by it. Such an agreement should be accepted because it provides a reasonable conciliation of interests and objectives. It should not be forced on participants by the authority or prestige of bargainers. High-titled officials are apt to be too far from the reality of day-to-day relationships to be well suited for singlehanded negotiations. Their prestige and authority may best be held in reserve, in part to settle issues on which the bargaining representatives cannot agree and in part to join in recommending acceptance of such agreements as are reached.

"*Lawyers as representatives.* Some current practice places negotiations in the hands of lawyers for each of the parties. They become the official spokesmen, lead the discussions, and work out the language of resulting agreements. Their imprint is clearly evident on many current agreements. This tendency to delegate bargaining to lawyers is frequently deplored by both employers and union officials. They insist that lawyers are too legalistic in their approach and that resulting agreements are likely to be framed in language that is replete with meaningless or complicated legal phraseology.

"Such generalizations are only partially true. Some lawyers who have specialized in industrial relations law can and do make valuable contributions in negotiations. Others, if they give only infrequent attention to this type of work, may seek to transfer practices developed in other fields of law to industrial relations. Here the results may be unfortunate. Lawyers who are not familiar with the language, practices, and techniques of industrial relations may be a genuine handicap to satisfactory negotiation. In any case, they should sit in as advisers to negotiators rather than as chief spokesmen for the parties. As advisers, they frequently contribute a degree of reasonableness and impartiality that helps greatly in reconciling conflicting viewpoints.

"*Group bargaining.* When employers bargain through a local association or unions through a special committee of the central labor union or local industrial council, representatives of the firm or local will presumably participate only indirectly in negotiations. Whatever agreements are reached become binding on all parties. The problem of ratification may be complicated in such situations. Local representatives must be two-way salesmen, first securing as many concessions as possible from the opposing party and then 'selling' the resulting contract to their sponsors.

"In some situations, local employer associations provide specialized bargaining representatives. These specialists, devoting most or all of their time to negotiation, develop a high degree of skill in negotiatory techniques. If unusual problems are involved, however (and most employers seem to feel that *their* problems are unusual), care must be taken to secure their full understanding before and during negotiations. The use of such specialized services tends also to introduce an element of 'patterns' in agreements. Such patterns may reduce local inequities and create uniformity in working conditions, but they may also be inappropriate for certain firms or unions.

"Local unions face similar problems when they are represented by outside officials from their international union or when they bargain through a city central or industrial council."

2.2.3 Physical setting for negotiation. Leonard Smith has provided an excellent statement of desirable physical sur-

roundings for bargaining sessions. His statement is as follows:*

"*Physical set-up of negotiations.* The physical set-up of the negotiating sessions bring with it a number of problems that have to be settled before collective bargaining commences. In the first place, the parties must decide where the sessions are to be held. For all practical purposes, this is simply a question of whether to locate the bargaining room within the company premises or in outside facilities. When the negotiations are held within the plant or on the company's premises, usually no costs are involved. Outside locations involve costs that may be met by the company alone or by both parties equally Some negotiators prefer to bargain at the plant; others prefer to be away from the company's premises. Where there are adequate facilities available on the company's premises, no special advantages or disadvantages are to be gained by using either location.

"One of the main problems to be considered in the selection of the bargaining room for other than single-plant bargaining is the geographical location When plants or companies are located in different areas, it may be difficult to get the two parties to agree on a given location. In fact, this becomes more complicated when the company's 'home office' or the union's 'international offices' are the groups to conduct the bargaining sessions. Such a situation may at times occur even in single-plant bargaining. Many solutions have been reached on this problem, among them the following:

1. Annual rotation of bargaining sessions among the sites of the various units concerned with the negotiations.
2. Selection of an outside site.
3. Alternating between management- and union-selected sites.
4. Agreement on a fixed site.

"*Negotiating room.* Adequate facilities include a room large enough to contain a table with sufficient seating capacity for all members of both bargaining committees and additional space for seating any observers. The room should be properly illuminated throughout the sessions—day as well as night. It should either be sound-proof or located in a quiet spot to prevent disturbances or interferences with the discussions or the thinking of the negotiators. Adequate ventilating facilities for the room are also important. All three of these factors affect the rate of fatigue and thus affect the negotiating abilities of the parties. Through proper care or control, the physical conditions in the room can be made comfortable and pleasant. Ash receptacles should also be provided. Their presence in the room serves to put at ease those negotiators who smoke. Another physical facility that also serves as part of the clerical needs of the negotiating sessions is a blackboard or some similar equipment, which will prove beneficial whenever one of the negotiators wishes to emphasize or clarify a point by making certain data visible to all participants.

"It is advisable to hold the collective bargaining meetings in the center of a series of three rooms, thus permitting each side to take a recess during the sessions whenever one is deemed necessary. Unless this is provided for, a vital phase of the bargaining process is neglected and the negotiations are unnecessarily prolonged. It is during such a recess that one side may decide to change its position or stand on specific points. A caucus held during a recess frequently leads to the realization that the stand taken should be modified if an agreement is to be obtained that will be advantageous both to the company and to the employees. These recesses are also valuable in permitting the negotiators to obtain relaxation from the strain and fatigue of bargaining. In this connection, it might be desirable to have the recess rooms equipped with easy chairs, a washroom, and possibly a bed. Such arrangements might be unobtainable, however, except in a hotel or at a club.

"*Clerical needs.* In addition to the availability of a blackboard, which can be considered as one of the clerical provisions of collective bargaining, there are a number of other clerical needs that should be considered. The first of these concerns stenographic services.

"There are two principal needs for stenographic services. One is the taking down of the verbatim discussion, and the second is the putting into writing of all

* Reprinted by permission from Leonard J. Smith, *Collective Bargaining* (New York: Prentice-Hall, Inc., 1946), pp. 40-42, 44.

points agreed upon prior to the final agreement."

2.2.4 Negotiating procedure. What are the appropriate procedures in collective bargaining or negotiating sessions? Who should act as chairman? Which of the parties should begin the presentation of demands? How is order preserved?

Some of these questions may be answered either by the terms of the contract still in effect or by tradition. For example, contract terms may specify that each party shall notify the other at least 60 days before the expiration date of any changes or modifications to be sought in negotiations. In that case, both parties will have had the preliminary statement of issues, and discussion may be started as soon as the session is convened.

An excellent guide for collective bargaining has been prepared by the Industrial Relations Division of the National Association of Manufacturers. It describes appropriate procedure as follows:*

"*Management Committee*

1. Because collective bargaining and the provisions of the contract agreed upon are of major importance to the life of the business enterprise, great care should be exercised in the selection of the management committee which will participate in the negotiations.

2. This committee should include one or more responsible top operating executives of the company, who are thoroughly informed on all phases of the business, the industrial relations executive, and, where deemed desirable, competent counsel fully versed in labor relations.

"*Who Conducts Negotiations*

1. Top management should not delegate to an outside agency the responsibility of conducting negotiations except in cases where unusual circumstances may make that course necessary.

2. One individual from the management committee should be selected to conduct actual negotiations for the employer. He should act as the spokesman for the management committee and have the authority to make decisions for the company within limits; these limits should be clearly known in advance to all members of the management committee.

"*The Role of Counsel*

1. Competent legal or other counsel, thoroughly experienced and informed in the sphere of labor relations, should be available to the management committee for consultation prior to and during the course of the negotiations.

2. It is not generally considered desirable for the legal counsel to conduct actual negotiations.

3. Legal counsel should review the language of proposed contract clauses before final agreement is reached.

"*Negotiation Meetings*

1 Under most conditions, negotiation meetings should be held on company property; however, there will be cases where circumstances or custom dictate otherwise.

2. Negotiations should not be carried on for more than several hours at a time. A short recess presents an excellent opportunity for reflection and, frequently, brings with it a new point of view.

3. It is sometimes desirable to postpone negotiations, so that both parties may have an opportunity to review and to restudy the issues in question.

"*Negotiating Committees*

1. Because collective bargaining also serves as a two-way channel to improve the employment relationship, it may be desirable that a union representative, union committee, or union negotiator be accompanied by a group of employees. This practice permits employees to see at first hand that management is conducting the negotiations in good faith and is dealing fairly with them. It also affords management an opportunity to

* *Management Guide for Collective Bargaining*, pp. 11-19. Reprinted by permis-

educate its employees in the problems of management.

2. In some instances, however, it is advisable for both negotiating committees to be small in number.

Negotiation Techniques

"Presentation of Management Proposals

1. Management has the clear right to formulate and to present its proposals for negotiation.

2. Where possible, management should assume leadership in negotiations by having its proposals serve as the basis for negotiation.

3. Management should submit counter-proposals at different times during the course of negotiations as evidence of bargaining in good faith.

"Where Union Presents Its Demands

If management is presented with a draft of the proposed contract by the employees or their representatives, it will be helpful to follow these procedures:

1. Sometimes this draft is forwarded to management through the mails, thus giving management the opportunity to study its contents before beginning negotiations.

2. In other instances, the proposed contract is presented to management at the first negotiating meeting. When this happens, management should *not* attempt to enter into negotiations immediately but should instead take sufficient time for a thorough study of the proposed provisions. It is desirable, however, for management to give evidence of its intention to proceed promptly with negotiations.

3. After careful study of the proposed contract, management will find it very helpful to prepare, for its own use, a check-list of the clauses therein, classified as follows:

a) The clauses that can be accepted as written.

b) The clauses that would be acceptable if amended.
In this case management should revise the clauses in question and be prepared to present them to the union with factual and reasonable explanation for the changes when the opportunity arises.

c) The clauses that are ambiguous, and in which the real meaning or intent is not clear.
With respect to such clauses, management should seek to determine the actual principle or thought incorporated therein and, if acceptable, revise the language so that the intent is clearly and directly stated.

d) The clauses that the company cannot accept.
In connection with this last group of clauses, management should be prepared to give the union clear and specific reasons why they are not acceptable.

These check-lists will be helpful in keeping management on the alert during the course of negotiations and will afford management the opportunity of taking a constructive position when the acceptable provisions are in discussion and advancing reasonable arguments against the provisions that are unacceptable.

4. Because many clauses of the contract are affected by others, it is inadvisable to make the final decision upon any provision in advance of reaching agreement on the contract as a whole.

"General Discussion of Demands

1. In the first discussion of a proposed contract, a general exploration of the objectives and viewpoints of both parties will be helpful.

2. If the proposed contract has been presented by the union, it is desirable to begin the negotiations by having the union representatives or negotiators first explain each point contained therein.

"Management's Course

1. Management may then proceed to explain the company's position on such points as may be in dispute, and by that explanation reveal the unsoundness of any point and the effect it may have on the future course of the company's business. This type of objective discussion

will clarify the significance of each point and facilitate the meeting of minds.

2. By the leadership it exercises in the conduct of negotiations, management can help materially in restricting the area of disagreement and thereby enlarge the area of agreement, thus utilizing collective bargaining as a valuable instrument for cementing good relations between employer and employees.

3. As collective bargaining proceeds, management should discuss the various points with plant supervisors, to the extent feasible, since they are the individuals who in actual practice carry out the terms and conditions of the agreement in their daily relations with the employees they supervise.

"Avoid Deadlock

It is desirable that every effort be made to avoid a deadlock. In every instance where a stalemate looms, it is the responsibility of both management and the union to explore the problem in point, discuss it constructively and from all angles, and keep the door open for suggested solutions.

"Retroactive Factors

Any retroactive proposals with respect to any particular issue or provision under negotiation should be carefully thought through, and a fair retroactive period of definite duration should be agreed upon by both the union and management prior to the start or during the course of negotiations.

"Language of Clauses

1. All clauses should be clearly understood by both parties and the language should express that understanding clearly and without ambiguity, so that the contract may be carried out in a spirit of good will. Ambiguously worded clauses are obstacles to sound employment relations because they cause differences in interpretation and are potential breeders of dispute.

2. The language of proposed clauses should be carefully reviewed by competent legal counsel as negotiations continue, and the draft of the proposed written agreement should be finally reviewed by counsel before it is finalized by signature.

"Finalizing the Agreement

1. If an agreement is reached between the company and the union there should be no delay in reducing it to writing and having it properly signed.

2. The terms and conditions of the agreement reached as a result of collective bargaining negotiations should be specific, definite, and complete, as of the date of signing."

2.2.5 General or specific statements. Should the resulting agreement be a contract that specifies relationships in detail? Or should it be an informal agreement that outlines the general principles on which the parties agree and leaves the details of implementation to day-to-day operators? This is a question on which much argument has turned. Many experienced parties, having operated under informal, general agreements for years, insist that the shorter the document the better. Many others, equally experienced, express a strong prejudice in favor of detailed provisions covering each phase of the relationships.

This difference of opinion appears to be closely related to the practices or intentions of the parties with respect to contract administration. If the day-to-day relationship is to be of the "arms-length" type, in which one or both parties insist on the letter of the agreement, then a specific and detailed contract is essential. If, on the other hand, administration is to be of the mediatory or "clinical" type, with representatives of each party seeking to apply the general principles of the agreement and willing to make adjustments and modifications in the interest of friendly cooperation, then much less detail is necessary. No clear-cut trend toward one type or the other has yet developed. Nor does such a trend appear likely so long as these sharply different attitudes and practices in administration continue.

2.2.6 Contract administration. Collective bargaining has only begun when an agreement has been negotiated. Although

FIG. 4.8 INTERPRETATION OF NEW CONTRACT CLAUSES*

63. Minutes shall be kept of all Labor Relations Committee meetings. These minutes shall be signed by representatives of the Local Union and the Company, and sufficient copies shall be furnished to all Committee members, an accredited representative of the Local Union, *and one each to the Union's International Office and the Industrial Relations Department of the Company. The foregoing shall be the responsibility of the Labor Relations Committee.*

Copies of minutes are also to be forwarded to the Union's International Office and to the Company's Industrial Relations Department. Responsibility for preparation and distribution of minutes has been made the joint responsibility of the Company and Union members of the Labor Relations Committee. From the practical standpoint, the Company will probably have to continue to do the work involved.

SECTION VII. *REVIEW BOARD*

64. *To assist in the attainment of the mutual objectives of the parties as set forth in this Agreement, promptly after the execution of this Agreement there shall be established a Review Board.*

New.

65. *Composition*

The Review Board shall be composed of ten (10) members, five (5) of whom shall be appointed by the Union and five (5) of whom shall be appointed by the Company. At least three (3) of the members appointed by the Union shall be chosen from the Executive Board of the International Union, and at least three (3) of the Company members shall be representatives of departments at its Minneapolis executive offices. Six (6) members shall constitute a quorum, but in the event of unequal representation, only an equal number of Company and Union representatives shall be entitled to vote on matters brought to a ballot. Each party shall designate a co-chairman, and such two co-chairmen shall jointly carry out any functions of the Board as may be delegated to them.

66. *Meetings*

The Review Board shall conduct regular meetings not less than once each quarter and special meetings upon written request of either party to consider any grievances referred to it by a plant Labor Relations Committee. All regular and special meetings of the Board shall be held at such place or places as may be jointly agreed to by the two co-chairmen.

This provision establishes a joint committee, comparable to the plant Labor Relations Committee, to deal with the company-wide aspects of the labor-management relationship under the Master Agreement. This approach is an experiment which the Union and the Company have agreed to try in the hope that with continuing machinery of this nature, we can more effectively deal with the areas of disagreement which continue to crop up during the contract year, in spite of the fact that to all intents and purposes, a satisfactory agreement was reached during contract negotiations. The new Board takes over the International Officer-Company executive discussions which previously operated at the Fourth Step of the grievance procedure and at the equal-committee phase of the arbitration procedure. In addition to this function in the formal grievance procedure, the Board may develop interpretations of Master Agreement provisions and deal with disagreements and problems which arise outside the provisions of the agreements. The composition of the Board has been made flexible so as to provide adequate local representation for the discussion of matters relating to a single plant.

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many controversial issues may have been compromised or otherwise eliminated, the agreement can at best only state the intentions of the parties. It is a statement of bilateral policy. Its implementation and application must be developed in day-to-day operations and relationships. Various programs must be planned

and instituted to effectuate the terms of the agreement. Development and maintenance of these programs and interpretation and application of the agreement to working conditions and relationships are described as *contract administration.*

In effect, the contract is administered by all who work under its terms. Major responsibility for its administration falls, however, on supervisors and management, on the one hand, and, on the other, on union representatives, including shop stewards, business agents, and other officials, as well as designated members of shop committees and grievance committees.

A major problem in contract administration is explaining a new contract to all who must interpret it. New provisions for which no meanings and procedures have been established may require careful explanation. Since many of those who must interpret the new clauses will not have participated in the negotiations, they will not know precisely what the negotiators had in mind when the clauses were written. They must be advised on these points.

Bargaining representatives sometimes prepare special interpretive bulletins to explain the context and meaning of troublesome clauses. The new agreement may be compared with the old agreement so that significant changes and modified relationships can be pointed up. Figure 4.8 illustrates the technique employed by one large industrial relations division. Each paragraph of the new agreement is identified as the same as or different from earlier provisions and the detailed meaning of all new clauses is explained in a parallel column on the same page.

2.3 UNION RECOGNITION AND SECURITY

Throughout the several hundred years that unions have existed, many attempts have been made to curtail their operation and growth. Employers and their associations have used a variety of devices—labor injunctions, yellow-dog contracts, and many others—to discourage union membership and to weaken unions. As a result, negotiations always involve some defensiveness on the part of unions, and many of the demands made by union representatives are related to "union security."

The term "union security" as it is now used refers to the status of the union, the protection of its interests and activities, and the means provided for assuring its continued acceptance as the representative of employees. These issues may arouse highly emotional reactions. Members will fight to insure the continued status of the organization. Here is how one conference notebook puts it:*

"Every member who considers the union as an important instrument in achieving the first four objectives (maximum income, job security, individual security, and 'working conditions') will be anxious to be sure that the union is strong enough to achieve them. Therefore the union seeks to be recognized as a participating party in the decisions affecting its members. Of course, such participation and such support come not only from the actions and agreements of the employer but also from the effectiveness of its own organization and leaders."

2.3.1 Types of Union Recognition. Unions seek recognition in order to protect themselves from attack, to better control their members, and to assure performance and observance of labor agreements. They insist that employers recognize the union as the responsible agent and representative of employees. In some cases, unions are granted exclusive powers to represent employees—even to the extent that only union members will be hired. To facilitate this arrangement—generally described as the "closed shop"—employers may actually delegate the selection and recruitment of new employees to the union. In other situations, lesser degrees of recognition are granted.

* *Notebook for First Year Members, Third Annual Steel Workers' Institute,* University of Illinois, 1949, p. 2.

The several common types of recognition have been described as follows:*

"Types of shop. As a further step in the development of union recognition and security, several types of limitations on employment have appeared. They represent varying degrees of control over labor supplies accorded to the union, ranging from one extreme in the 'open shop' to the other extreme in the 'closed shop' with a 'closed union.' In addition, several forms of 'checkoff' may be established to assure the union that members will pay their dues and otherwise maintain their good standing in the union.

"Closed antiunion shop. The closed antiunion shop is no longer widely established, although there may be managements in a few localities that still approximate this arrangement in their employment policies. In it, no unionists are accepted for employment. This type of discrimination was not unusual in the period before public policy and legislation approved collective bargaining. It was frequently associated with and enforced through the *yellow-dog contract,* by which an employee agreed not to be or become a member of any union during the term of his employment. The National Labor Relations Act of 1935 made such practices illegal in the industries to which it applied.

"Open shop. In the open shop, union membership is regarded as having no relationship to employment. Often described as the 'American plan' in years past, the open shop means that employment is open to all, union and nonunion alike. Since no attention is paid to union membership, no recognition is granted to a union, and no collective bargaining is practiced, under this arrangement. For this reason, the open shop has been attacked by unionists, who argue that it is an antiunion arrangement. They insist also that it was frequently a screen or cloak for the closed, antiunion shop. It is the open shop that Finley Peter Dunne had 'Mr. Dooley' describe when he said: 'What is th' open shop? Sure, 'tis where they kape the doors open to accommodate th' constant stream of min comin' in t' take jobs cheaper than th' min what has th' jobs.'

"Union shop. The union shop is presently the most common type of union security provision. In it, all employees are required to become union members within a stipulated period after they are hired and to remain members throughout their employment. Union membership is not a requisite for hiring, but after 30, 60, or 90 days—usually corresponding to the period of probationary employment—if an employee wishes to remain, he must join the union. Thereafter, the employee must retain his membership as long as the union-shop provision is in force.

"Under earlier union-shop provisions, if an employee was expelled from the union, he lost his right to continue on his job. Recently, however, under regulations imposed by the Labor Management Relations Act of 1947, discharge for loss of union membership may be enforced only if the expulsion is for nonpayment of dues, not for other offenses against the union. By this change, the authority of the union to discipline its members was obviously weakened.

"Maintenancé of membership. During World War II, when work stoppages could not be tolerated, maintenance of membership was established in many shops, as a compromise between union demands for a union or closed shop and employer refusal to grant such terms. The arrangement had been used in a few industries before the war, but the War Labor Board gave it wide usage and made it the most common form of union security.

"Under maintenance of membership provisions, present employees are given an *escape period,* generally of ten days or two weeks, when the arrangement is established. During the escape period, they must decide whether or not they wish to become or remain members of the union. At the expiration of this period, all those who are union members

* Quoted from Dale Yoder, *Manpower Economics and Labor Problems* (New York: McGraw-Hill Book Company, Inc., 1950), pp. 461-463.

must maintain their membership for the duration of the contract or agreement. New employees exercise the same option. If they join the union, they must remain in it for the duration of the agreement.

"*The Rand formula.* Another World War II contribution, originating in Canada, is the Rand formula, so called because it was advanced by Justice Rand as a basis for settlement of a Ford Motor Company strike in Canada in 1945. It is similar to what is sometimes described as an *agency shop*. It requires that all employees pay dues to the union, whether members or not, and further requires that the union poll all employees —members and nonmembers alike—in strike votes. It is designed to prevent 'free riders,' *i.e.*, employees who secure all the benefits resulting from union negotiation without contributing anything to the support of the union.

"*Preferential shop.* In the preferential shop, union members are given preference in hiring. Nonmembers are employed only if no union members are available. This type of relationship is general only in situations where a union has achieved recognition, generally as sole bargaining agent, and where collective bargaining is accepted. The preferential shop has a long history in certain industries, of which the building trades are an outstanding example.

"*Closed shop.* In the closed shop only union members may be hired. Employers may secure employees through union-controlled hiring halls or by asking a union official to supply candidates or otherwise. While an employer does not ordinarily have to accept members recommended or referred, his choice is restricted to union members.

"The *closed union* is not a form of union security contract provision. It is, however, closely related and frequently confused with such provisions. A closed union is one that shuts the door to all or specified types of applicants, thus limiting its membership. Any union may have such rules, but the term is generally used to refer to what are regarded as questionable or unreasonable limitations on admissions. For example, the fact that applicants must show a knowledge of painting to be admitted to the painters' union would not be considered evidence that it is a closed union, nor would it be objectionable. But requirements that new members of a union must be sons of present members, or members of a specified race, or that no new members will be accepted, or that membership may not exceed a prescribed number would justify such a designation.

"*The checkoff.* Another means of providing union security is the checkoff of union dues. Under checkoff provisions, management deducts specified union dues and fees from wages and remits the amounts involved directly to the union. The device was not widely used before World War II, although it had long been included in contracts negotiated by the United Mine Workers. During the war, many organizations, particularly the newer unions and those that were growing rapidly, sought and received checkoff provisions by order of the War Labor Board. Since the war, these provisions have become common in a wide range of industries.

"Two types of checkoff may be noted. One is described as *voluntary* and *revocable*. Under this arrangement, employees may (usually upon written notice to the employer) ask that deductions be made from their wages and forwarded to the union. They may discontinue this arrangement by a similar notice to the employer. Under *compulsory* and *irrevocable* provisions, however, union members are required to authorize the checkoff and cannot rescind their authorization."

2.3.2 Current practice. World War II popularized the membership type of union security, which represented a compromise between union demands for the closed or union shop and the insistence of employers that they would permit no special grants of additional union recognition because of the war. Immediately after the war, the federal Taft-Hartley Act prohibited the closed shop in industries involving interstate commerce. These developments are reflected in current practice, in which the union shop

has become the most common form of union recognition. Present arrangements provide for the union shop in about 60 per cent of all contracts, for maintenance of membership in about 15 per cent, and for designation of the union as sole bargaining agent in about 25 per cent. About two-thirds of all contracts include the checkoff.

2.4 MANAGEMENT SECURITY

Many managements appear as insecure as the unions with which they deal. Since increasing areas of employment relationships are being controlled through collective bargaining, the field of unilateral action open to managements appears to be narrowing. As unions have demanded the right to negotiate on additional conditions of employment, and as governmental administrative agencies have ruled that employers must bargain if requested to do so, many managements have come to fear that their range of action may be completely eliminated.

Since there is no simple criterion for identifying the areas in which managements should have a free hand, the question of how much freedom they should have often becomes a matter of economic strength. As a result, the question of management's rights has became a subject of bargaining in many situations. Two types of bargained contract clauses are notable. In one of them, the parties agree that all employment conditions not specifically mentioned in the contract are reserved for unilateral action by the management. In the other, areas in which management may act without consultation with the union are specifically designated.

Clearly, collective agreements may sharply modify management's earlier unrestricted rights. The right to hire and fire, for example, is obviously modified by closed or preferential shop arrangements and by clauses specifying procedures for discipline and discharge. Professor Douglass V. Brown has provided a clear statement of this change. He says: *

"*Management rights under the agreement.* We are now in a position to tackle more directly the question of the rights of management when a collective agreement is in effect. Put briefly, the rights of management are of two sorts. In the first place, there are those rights which may be explicitly set forth in the written agreement. In the second place, there are those rights which management has exercised in the past, and with respect to which no limitation is contained in the agreement.

"Superficially, this position may seem to bear a strong resemblance to the view that was earlier described as an extreme view and was rejected. Actually, however, there are important and far-reaching differences. The proposed approach contains no suggestion of prerogatives' or 'inalienable rights.' Those rights which management retains are simply those which it has *exercised* in the past and which the union and the employees may reasonably expect will continue to be exercised in the absence of specific limitation. Moreover, there is no suggestion that on those matters on which the agreement is silent, management is free to proceed as it chooses. Management has, in essence, bound itself by its past actions, and, if a freer hand is desired, it is incumbent upon management to initiate and carry through into the written agreement the provisions which will permit it to follow the desired mode of procedure.

"Viewed in the light of the preceding discussion, so-called 'management rights' clauses in the agreement are easy to appraise. If they merely re-affirm modes of procedure which management has clearly followed in the past, they are unnecessary and superfluous. (In this connection, management may want to consider the possible emotional reactions to an insistence upon a reaffirmation of

* Quoted by permission from Douglass V. Brown, "Management Rights and the Collective Agreement," *Proceedings of the First Annual Meeting,* Industrial Relations Research Association, 1948, 154-155.

management rights, and the price that may be exacted to assuage emotions.) If management rights clauses clarify or make explicit what have been vague and uncertain modes of procedure, or if they set forth new modes of procedure, they are significant. It may be added that, as a practical matter, causes which clarify existing modes of procedure or substitute new ones are more likely to find their appropriate place further along in the written agreement where substantive matters are discussed, rather than near the beginning whither it has become customary to relegate the more general 'rights' clauses.

"Before we leave the question of management rights under the agreement, one further point must be made. We have said that management has retained certain rights even though they are not specifically set forth in writing—those rights which it exercised prior to the agreement. But, by the same token, management cannot rely upon its exercise of previous modes of procedure if new modes of procedure are included in the written agreement. The written agreement supersedes past practice. If management has concluded an agreement, and if therein it has agreed to alter certain previous modes of procedure, it cannot then take refuge in past procedures or 'business necessities.' In the usual case, moreover, the clauses of the agreement are not unrelated, and the relations are important. Accordingly, management—or the union—is wise to scrutinize carefully the totality of the agreement. A provision which, taken by itself, may seem innocuous may, when taken in relation to other clauses, assume a stature that hinders the effective functioning of one party or the other."

2.5 EMPLOYEE REPRESENTATION PLANS

So far, we have made no mention of employee representation plans, although they have played an important part in the development of current practice. In such plans, employees become members of a plant-wide or company-wide organization. Their officers in the association are fellow employees, and their association maintains no relationships with outside or independent organizations of employees. Hence employee representation plans are often said to involve "company unions" or "dependent unionism."

Although several thousand such plans were in operation in this country in the years immediately following enactment of the National Industrial Recovery Act (1933), they disappeared rapidly after 1935. When interpretation of the National Labor Relations Act of 1935 held that if employers aided or assisted such associations they might be guilty of an unfair labor practice, employer support was withdrawn. Without that support, most of these organizations disappeared.

2.6 CODETERMINATION

In the years immediately following World War II, employers and unions in the United States were active in seeking to re-establish the productive capacity of Europe. Unions in this country played an important part in rehabilitating the independent or free unions of Germany, Italy, and France. In the course of this reconstruction, wide attention was attracted to German legislation providing for what has been translated as "codetermination." The arrangement provides for the appointment of union representatives to the boards of directors of firms in a manner that insures the unions of majority control. Organizations of American employers protested the legislation. The arrangement was by no means an innovation in Germany, however, having been in practice in a limited number of firms before the war.

2.7 UNION-MANAGEMENT COOPERATION

As a further extension of collective bargaining, a number of firms and unions in the United States have de-

veloped plans for what is usually described as union-management cooperation. The idea is by no means recent—such plans date back to the years immediately following World War I. In general, such arrangements seek to advance the mutual interests of employers and employees through close cooperation in efforts to improve efficiency and reduce waste. To that end, special cooperative committees are established to plan and develop cooperative programs. These programs extend considerably beyond the usual areas of collective bargaining.

Ernest Dale has studied the operations of several hundred of these programs and has reported on their objectives and effectiveness.* He reports that the first objective of such plans is generally economic, since they seek "to raise the company's revenue-paying capacity" and thus to provide more for all. A second objective is to provide for more effective two-way communication between employer and employees. "For management it is a way of pointing to production needs and acquainting labor of its position. . . . For labor it is an instrument for communication upward." A third objective is, in Dale's opinion, social. Managements, he says, see cooperation as a means of improving industrial relations. Labor, he says, sees cooperation as a means of providing an opportunity for "non-economic aspirations."

Cooperative plans may be either departmental or plant-wide. Dale found departmental cooperation in 145 of the 228 reporting concerns. Most areas of cooperation are those in which conflicting interests are at a minimum and mutual interests at a maximum. They are also areas in which both management and labor are experienced. Such controversial subjects as wages and hours are generally avoided. Dale has provided a summary of the most common subjects of cooperation, as shown in Table 4.5.

* Ernest Dale, "When Labor Cooperates with Management," *Advanced Management*, Vol. 14, No. 3, September 1949, 101-106.

TABLE **4.5** SUBJECTS OF UNION-MANAGEMENT COOPERATIVE PROGRAMS*

	Number of times mentioned		
	Departmental cooperation	*Plantwide cooperation*	*Total*
Accident prevention	87	76	163
Elimination of waste and defective work	106	41	147
Furthering labor understanding of policies	97	48	145
Regular attendance	84	31	115
Employee insurance plans	68	42	110
Quality control	84	21	105
Job evaluation	52	50	102
Physical working conditions	65	36	101
Lateness	80	20	100
Maintenance of tools, fixtures, etc.	74	24	98
Employee health	71	26	97
Methods improvement	67	29	96
Discipline control	65	23	88
Training, apprenticeship, and induction programs	55	30	85
Labor turnover	50	19	69
Setting output standards	42	26	68
Incentive systems	42	25	67
Production planning	45	14	59
Promotional programs	39	14	53
Utilization of machinery	43	8	51
Employment stabilization	37	12	49
Technological changes	37	11	48

* Reproduced by permission from Dale, "When Labor Cooperates With Management," 103.

Cooperative programs appear to be increasing rapidly. Once established, plans are likely to be retained (20 per cent of the plans studied by Dale had lasted from five to ten years). Firms report that the plans have resulted in improved relationships with employees as well as increased productivity. In general, plans started during periods of prosperity appear to be more successful than those undertaken in time of distress.*

3. RELATIONSHIPS WITH INDIVIDUAL EMPLOYEES

Although the scope of collective bargaining has widened since enactment of the National Labor Relations Act, bilateral action is by no means as broad as the area of employment relationships. On many points, employers still deal with individual employees as individuals. These areas include what are widely regarded as the "personnel" phases of employment relations, as distinguished from the "labor relations" or collective-bargaining aspects described in the preceding section.

The distinctive characteristic of these "personnel" phases of manpower management is that employers deal with employees as individuals—the relationship is personal. In many business organizations, this distinction is regarded as sufficiently important to justify a special division in the "employee relations" or "industrial relations" department. Such a division may be headed by a personnel manager whose position is parallel to that of the labor relations director.

So distinguished, the principal "personnel" functions may be described briefly as follows. They include the several functions involved in staffing—that is, providing manpower in the proper quantities and with the necessary qualifications for all positions in the organization. These staffing functions include job analysis, by which individual job requirements in terms of manpower are defined. They include the preparation of staffing schedules or manning tables in which these requirements are outlined and summarized. They include the recruitment and selection of manpower according to the specifications outlined in staffing schedules. They include placement and induction of new employees and the training of both present employees and recent recruits. Supervisory training must be provided for those who are promoted into positions in which they have supervisory responsibilities. Personnel rating may also be provided and included in these responsibilities. In summary, then, the principal "personnel" functions are:

1. Staffing, which includes,
   - Job analysis
   - Preparation of staffing schedules
   - Recruitment
   - Selection
2. Placement and induction
3. Training
4. Personnel rating

3.1 STAFFING

No uniform or standard category of "employee" is feasible. Since requirements vary from job to job, the manpower appropriate for one position might be useless in another. Some jobs require skilled manpower; others require a minimum of skill. Some positions involve the constant application of specialized training; others make no such demands. Some jobs may be filled simply by upgrading employees from preparatory or training positions. Other jobs may require skills possessed only by persons who have served extensive apprenticeships.

There is no such thing, then, as a standard "man" or a standard unit of manpower. Rather, manpower requirements must be stated in terms of the particular requirements of the positions that are to be filled. As a beginning,

* For additional information, see also Robert Dubin, "Union Management Cooperation and Productivity," *Industrial and Labor Relations Review*, Vol. 2, No. 2, January 1949, 195-209.

therefore, the specific manpower requirements of each job must be determined. A summary of these requirements will provide a staffing schedule for the organization as a whole. Although the responsibility for appropriate staffing is clearly that of the line organization, the function of determining job requirements and building and maintaining a staffing schedule is so specialized that it is often delegated to the personnel or industrial relations department.

3.1.1 Job analysis. The usual procedure employed in discovering the personnel requirements of jobs is job analysis. Job analysis involves a careful study of each job to find out just what the job includes, what the job-holder does, how he does it, under what conditions the job is performed, and what special qualifications the job-holder must have.

The term "job analysis" is frequently confused with several other similar, and in some cases related, terms. Among the most commonly confused terms are:

Job description: the name given to the written and specially organized *summary* of significant findings from job analysis.

Job specification: the *outline of personal qualifications* regarded as essential for each job—a product of job analysis.

Job evaluation: the process of identifying and measuring the *factors in each job for which compensation is paid,* and hence a device used to determine rates of payment.

Job classification: a procedure involving the *grouping of jobs,* sometimes according to the nature of the functions performed—as accounting or drafting or engineering—sometimes according to rates of compensation, and sometimes on other bases.

Carroll L. Shartle has provided an excellent summary of the essential nature of job analysis in the following selection from his book, *Occupational Information:**

"Job analysis is an intensive, direct method of obtaining the pertinent facts about jobs. It includes the observation of the job and the reporting of facts which are observed and which are obtained in conversation with workers, supervisors, and others who have information of value. Job analysis is a basic method which is widely accepted throughout industry. It is also used extensively by both military and civilan government.

"One must be careful to differentiate job analysis from worker analysis. This is not always easy to do. In worker analysis one studies the workers who are performing jobs to discover the characteristics the workers themselves possess. This may be by an interviewing, testing, or examining technique. In job analysis one will observe workers but one is primarily seeking information about the job rather than about the workers who are presently employed in it. It is true that studies of workers yield information which is helpful in understanding jobs, but job analysis as used in this volume is a method which involves observing the duties of jobs, obtaining facts about the qualifications required, and other data about the job itself rather than about any individual worker who happens to be employed in the job at the time the analysis is made.

"The original establishment of a job analysis program or the revision of such a program to meet the needs of personnel problems requires the establishment of a plan which will meet all the needs of the industrial or business firm, educational institution, government agency, or other organization that desires to prepare such analyses.

"In far too many instances where a job analysis program has been put into operation, it has been discovered six months or a year later that the scope of the analyses was incomplete for certain uses. The analyses are then made over again to secure information that could have been obtained easily in the first instance if a careful plan had been drawn up. In one situation a plant initiated a job analysis program which did not cover any items pertaining to the physical requirements for the jobs. The plant had to go over its jobs again

* Second ed. (New York: Prentice-Hall, Inc., 1952), pp. 29-31.

to discover these facts in order to aid in the employment of disabled persons.

"The contents and scope of a job analysis program depend upon the uses which are to be made of the occupational information obtained from such analyses. Thus the first step in organizing such a program is to discover the various uses that are to be made of the information. This survey should be exhaustive, but it can be done quickly.

"Such a survey means that the individual in charge of planning the program should visit personally the various units in the establishment and discover the uses each department is to make of such information. For instance, the job analysis program may be under the direction of the wage analysis division in the establishment. It would be most unfortunate if a program were put into effect which only obtained the required information for this division, when, with a little extra work, the needs of all divisions could be met. Thus additional surveys and analyses of jobs by the training division, the employment division, the safety division, and other units would not be necessary.

"During the survey each probable user of occupational information should be contacted and the specific kind of information needed should be recorded. Thus, for example, the training division might list the following needs for up-to-date occupational information.

"A detailed description of the work performed showing the specific knowledges required. Also the relation of each job to other jobs, in order that the amount of extra training required for transfer to related jobs can be estimated."

3.1.1.1 Job, position, and occupation. In order to recognize the interrelationships among "jobs," "positions," and "occupations" in job analysis, we must first define the terms. A job is a combination of tasks, duties, and responsibilities generally regarded as the usual assignment of an individual employee. A position—as distinguished from a job—is a job performed by a specific employee. The position is both the job and the particular employee performing it at any given time. Hence a job may involve many positions. The job is impersonal; the position is personal.

An occupation is a generalized job; the term refers to a whole group or class of similar jobs common to several employers, industries, or areas. Thus the occupation of tool and die maker is widely recognized, as is that of printing pressman or machinist or stone-cutter. These are all skilled occupations. An example in the semi-skilled area is the machine operative. Common labor represents an occupation in the unskilled area.

3.1.1.2 Gathering job information. The three principal methods of securing job information are:

1. Circulation of questionnaires to all job-holders These questionnaires ask the job-holder to supply the several types of information sought in job analysis. They may, in addition, ask the immediate supervisor to examine and comment on the replies provided by the job-holder.

2. Interviews, used in place of questionnaires. This procedure, more common when the majority of job-holders have little experience in writing, merely substitutes the writing ability of staff members plus their ability to gain through conversation information that would not have appeared on a questionnaire.

3. Observation and job auditing by trained job analysts. This procedure has much to commend it. Specialized analysts combine interviewing and on-the-job observation to provide a more accurate and comprehensive (and at the same time discriminating) report than is usually secured by the use of questionnaires or unspecialized interviewers.

3.1.1.3 Questionnaire forms. No single questionnaire is appropriate for all types of jobs: However, most of them follow an outline that first identifies the job, then seeks information on the principal tasks involved, and then asks questions designed to discover the mental skill and physical requirements of a satisfactory job-holder. Also, one section usually requests information on any

FIG. 4.9 QUESTIONNAIRE FOR INDIVIDUAL JOB DESCRIPTION

Title of Position ....

Department .... Section ....

Division .... Date ....

Please read all of the questions before making any entries; then answer each one as briefly as possible, consistent with complete information. Return this description within one week to the Job Analyst, Personnel Department.

Description of Duties

1. What is the general purpose of your work?
2. What *duties* do you personally perform in the usual course of work? (Tell from where you receive your work, what you do with it and where you send it. In answering this question discuss your daily routine.)
3. What duties do you perform only at stated periods, such as weekly, monthly, etc.?
4. What occasional duties do you perform at irregular intervals?
5. How many employees do you supervise? (List job names and number of people in each job.)
6. To whom are you directly responsible?
7. What, if any, instructions do you receive as to how this work is to be done and from whom are they received?

Performance of Duties

A. Mental Requirements

8. What is the lowest grade of grammar school, high school or college education that should be required of a person starting in your position?
9. If any special courses are needed in order to perform your duties satisfactorily, name them.

B. Skill

10. What past experience is it necessary for a new employee to have in order to learn to perform the duties of your position? Name the kind of experience, where and how it could be obtained and the time required to secure it.
11. Having the above education and experience, what would a new employee have yet to learn and how long would it take the employee to obtain sufficient practice in doing the new work to reach the point at which he would be barely satisfactory?
12. In what lower positions could an employee receive training for your position?
13. For what higher positions in the company does your present work train you?
14. What, in your opinion, is the most difficult part of your work and why is it difficult?

C. Physical Effort

15. Roughly, what proportions of your time are spent in: Standing .. %, Sitting %, Moving about %, Other %?
16. What machines or other equipment do you personally operate; regularly or only occasionally?
17. Roughly, what proportion of your time is spent in operating each machine you use? State also what degree of speed is required on each machine.
18. What, if any, are the physical requirements for the proper performance of your duties? (Strength, height, dexterity, etc.)
19. Please list any other requirements not covered above and any personal qualifications and characteristics which you believe a candidate for your position should have.

Responsibility

20. What is your responsibility for money, securities or other valuables?
21. What is the nature and extent of your responsibility for the employees under your supervision?

22. Give the nature and extent of any responsibility you may have other than for men or money?

23. What personal dealings with customers do you have in performing the duties of your position? State the nature of your business with the customers.

24. Roughly, what proportion of your time is spent in dealing with customers?

Working Conditions

25. What are your usual working hours?

26. What are the disagreeable features of your work?

Use this space and additional sheets of paper, if necessary, for any special features of your work not covered above, and for answers to questions for which more space is needed.

Your name ....

Years in this position . ...

FIG. **4.10** JOB SPECIFICATION FOR JOB ANALYST*

Title—Job Analyst

Alternate Titles—Labor Analyst, Job Analysis Manager, Head of Job Study

Promotion to—Personnel Research Director, Employment Manager

Promotion from—Personnel Clerk, Job Rater

Duties—The Job Analyst secures job information on all factory and office jobs for the employment office so that the most efficient placement may be obtained. He develops questionnaires and job description forms; audits individual jobs; writes job descriptions and job specifications; may rate and grade positions in the shop and office; may correlate wages and salaries in the firm with comparable wages and salaries of other companies as a guide to management; works on and adjusts job evaluations as a basis for raises, promotions, and rate complaints; may use techniques of time and motion study in job analysis; may supervise job breakdowns; checks and approves proposed and existing classifications on an individual case basis; analyzes shift schedules; prepares records and charts required to furnish management with details of the duties of each position and the interrelationships among positions.

Responsibility for Policy—Makes policy recommendations with respect to job analysis and evaluation to the Employment Manager.

Initiative Required—Some initiative is needed in developing and administering improved job analysis methods.

Responsibility for Work of Others—Assigns and supervises work of personnel clerks, job raters, and stenographers.

Training—Much of the training for this position must be obtained on the job.

Working Hours—Same as office employees.

Qualifications for Employment—

Sex: Either.

Education: A college degree with a major in industrial relations or industrial engineering is desirable. Important college courses are advanced statistics, personnel psychology, office management, labor legislation, occupational analysis, classification, and compensation.

Experience: Previous training in industrial job analysis, evaluation, and wage and salary correlation is recommended.

Personal Qualities: Ability to observe details meticulously, ability to approach problems objectively, ability to differentiate important from unimportant details.

Mental Ability: Equivalent to a college graduate.

Special Knowledge: Familiarity with specialized tools, machinery, and terminology of occupations within the industry.

* From Kriedt and Bentson, "Jobs in Industrial Relations," 27.

unusual working conditions. Figure 4.9 provides an illustration of one such form.

3.1.1.4 Qualifications of job analyst. Figure 4.10 is a generalized job specification for the job analyst—the specialized technician who analyzes jobs and prepares job descriptions.

3.1.1.5 Job descriptions and specifications. In the usual procedure, job analysis provides information that is first recorded in the job *summary*—often the notes prepared by the job analyst—and is then written up in more formal style to provide a job description. From the job description, a variety of specialized reports may be prepared. For example, an examination of job descriptions may disclose the nature of training needs. Or the recorded facts may provide information for job evaluation or for setting grievances.

For staffing purposes, a job specification is extracted from the information provided in the job description. The "job spec" summarizes the personal requirement for the job and specifies the manpower requirements. It indicates the sex, age, education, skill, experience, and other personal characteristics required.

3.1.2 Staffing schedule. The staffing schedule, or manning table, or personnel inventory, combines the information provided by the job description with the number of job-holders required for each job. Thus it creates an over-all summary of manpower requirements for the organization. Such tables are by no means universally available. Indeed, during World War II, when such manning tables were widely used by Selective Service in acting on requests for deferments, many firms found themselves without tangible evidence of their needs. Figures 4.11 and 4.12 are illustrations of such tables.

3.1.3 Staffing procedure. Except in the case of new plants which require recruitment of an entire labor force, usual procedure involves the filling of vacancies and the provision of such additional personnel as may be required for expanded operations. Those who are responsible for recruitment ordinarily receive requisitions for whatever additional manpower is required. These requisitions indicate the job title, job number, and how many persons are to be recruited. Reference to job descriptions or specifications indicates what personal qualifications must be met by the new job-holders. The recruiters may then effect transfers and promotions from within, or they may seek to find the desired manpower from other sources.

3.2 RECRUITMENT

Principal sources from which employees are drawn to fill requisitions include:

1. Inside sources, i.e., present employees who are ready for promotion, who have requested transfer, or who are about to be laid off because of reduced operations in another department.

2. Friends and acquaintances of present employees who can be reached by announcing vacancies to present members of the work force.

3. Applicants "at the gate"—the persons who come to the employment office seeking work.

4. The waiting list—the file of applications taken in preceding months and maintained on an active basis.

5. Public employment offices maintained by city or state.

6. Private employment services maintained as commercial ventures.

7. Unions, especially the unions represented among present employees, and more particularly those active in the management of hiring halls.

8. Schools and colleges, the usual sources of new employees for positions requiring special training.

3.2.1 Techniques and devices. Among the most commonly used recruitment techniques are the following:

1. *Labor scouts.* These are traveling representatives of the employer who visit promising sources and encourage potential employees to make application. For example, they may visit schools and colleges; they may journey to other

PLANT JOB NUMBER	OCCUPATIONAL IDENTIFICATION DATA			MINIMUM TRAINING (Months)	NUMBER NOW EMPLOYED		MINIMUM EXPERIENCE or TRAINING REQUIRED OF NEW WORKERS in MONTHS				UPGRADED	
	PLANT JOB TITLE	U S E S. OCCUPATIONAL DICTIONARY JOB TITLE	U S E S. D O T. CODE		Total	Female	SAME JOB	RELATED EXPERIENCE	VOCATIONAL TRAINING	TECHNICAL TRAINING	From	To
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
			PRODUCTION LATHE DEPARTMENT (6)									
1	Foreman	FOREMAN (mach. shop)	5-92.768	60	3	0	6	12	0	0	2	-
2	Lathe Hand First Class	ENGINE LATHE OPERATOR I	4-78.011	24	22	0	6	12	0	0	3	1
3	Lathe Hand Second Class	ENGINE LATHE OPERATOR II	6-78.011	4	66	6	0	6	6	0	4	2
4	Drill Press Opr.	*DEEP-HOLE DRILLER (mach. shop)	6-78.011	3	3	1	0	6	6	0	5	2
5	Saw Operator	*BAND-SAWING-MACHINE OPERATOR	6-78.611	2	2	1	0	0	0	0	6	4 or 3
6	Helper	*MACHINIST HELPER	8-78.10	0	9	0	0	0	0	0	-	4 or 5
				GRINDING	(105) DEPARTMENT	(8) (6)						
11	Foreman	FOREMAN (mach. shop)	5-92.768	60	2	0	6	12	0	0	13	-
12	External Grinder	CYLINDRICAL-GRINDER OPERATOR II	6-78.521	4	9	2	0	6	6	0	15 or 16	
13	Internal Grinder	INTERNAL GRINDER OPERATOR I	4-78.512	20	2	0	6	12	0	0	12 or 14	11
14	Centerless Grinder	CENTERLESS-GRINDER OPERATOR	6-78.511	10	9	2	0	6	6	0	15 or 16	13
15	Burrer	*BURRER, HAND	6-77.510	2	2	2	0	0	0	0	-	13
16	Trucker	*TRUCKER, HAND	8-78.10	0	2	0	0	0	0	0	-	15

* Entry Jobs

FIG. **4.11** PERSONNEL INVENTORY OR MANNING TABLE.

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PART I — PLANNING TABLE — OCCUPATIONAL INFORMATION DATA

LINE NUMBER	OCCUPATIONAL IDENTIFICATION DATA			MINIMUM TRAINING TIME ( )	PRESENT NUMBER EMPLOYED					PERCENTAGES (OPTIONAL)		NUMBER IN TRAINING	JOB TO BE RE-ENGINEERED (JOB BREAKDOWN)	
	PLANT JOB TITLE	OCCUPATIONAL DICTIONARY JOB TITLE	DICTIONARY CODE		WHITE		OTHER		TOTAL	BY DEPT	BY PLANT			
					MALE	FEMALE	MALE	FEMALE						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14

PART II — PLANNING TABLE — ADDITIONAL FUTURE LABOR NEEDS

LINE NUMBER	SUPPLIED FROM WITHIN PLANT		RECRUITED FROM OUTSIDE PLANT										
			MONTHLY REQUIREMENTS					MINIMUM EXPERIENCE REQUIRED					
	UPGRADED	TRANS-FERRED	CURRENT MONTH	2ND MONTH	3RD & 4TH MONTH	5TH & 6TH MONTH	TOTAL 6 MONTH	SAME EXPERI-ENCE	RELATED EXPERI-ENCE	VOCATIONAL TRAINEES	INEX-PERIENCED		
	15	16	17	18	19	20	21	22	23	24	25	26	27

PART III — PLANNING TABLE — REPLACEMENT SUMMARY (FOR SELECTIVE SERVICE)

LINE NUMBER	PLANT JOB TITLE	DICTIONARY CODE (OPTIONAL)	TOTAL NUMBER OF WORKERS	NUMBER OF WOMEN	MALE WORKERS 38 AND OVER OR UNDER 18			MALE WORKERS 18 THROUGH 37			
					45 AND OVER	38 THROUGH 44	UNDER 18	PHYSICALLY DIS-QUALIFIED	WITH CHILDREN	MARRIED WITHOUT CHILDREN	SINGLE
	28	29	30	31	32	33	34	35	36	37	38

FIG. **4.12** MANNING TABLE INFORMATION FOR SELECTIVE SERVICE

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industrial areas; they may even seek new employees in foreign nations.

2. *Advertising*. Various types of advertising may be useful in recruiting. Perhaps the most common is the classified advertisement in metropolitan newspapers. In some cases, larger advertisements are used, however, and ads may be placed in trade journals.

3. *Posters*. Announcements of job opportunities may be placed in business houses throughout appropriate communities. In some cases, billboard advertising has been used effectively, especially in staffing new plants.

3.3 SELECTION PROCESS

Recruitment is a positive process; it acts to secure appropriate applications. In contrast, selection is negative; it seeks to eliminate the least promising candidates and to discover those that appear most likely to succeed. The selection process may be simple; it may consist merely of referring applicants to the supervisor with whom they are to work. On the other hand, the selection process for important positions may be quite complicated and extensive, involving several steps or stages. It may begin, for example, with the acceptance of an application blank. That step may be followed by a series of interviews, tests, and perhaps a formal tryout or probation period.

Figure 4.13 reproduces Uhrbrock's flow chart of selection procedure. This is by no means indicative of the steps to be taken in all selection. Rather, it notes various possibilities and suggests the care that is necessary if selection is to be highly effective in eliminating unlikely prospects and discovering the most promising.

3.3.1 Selection ratio. In order to compare the number of applicants considered and the number employed, a ratio is calculated in which the denominator is the total number of applications and the numerator is the number of applicants who are accepted for employment. This ratio may be examined from time to time to check on the quality of applicants and the volume of work being performed by those responsible for selection.

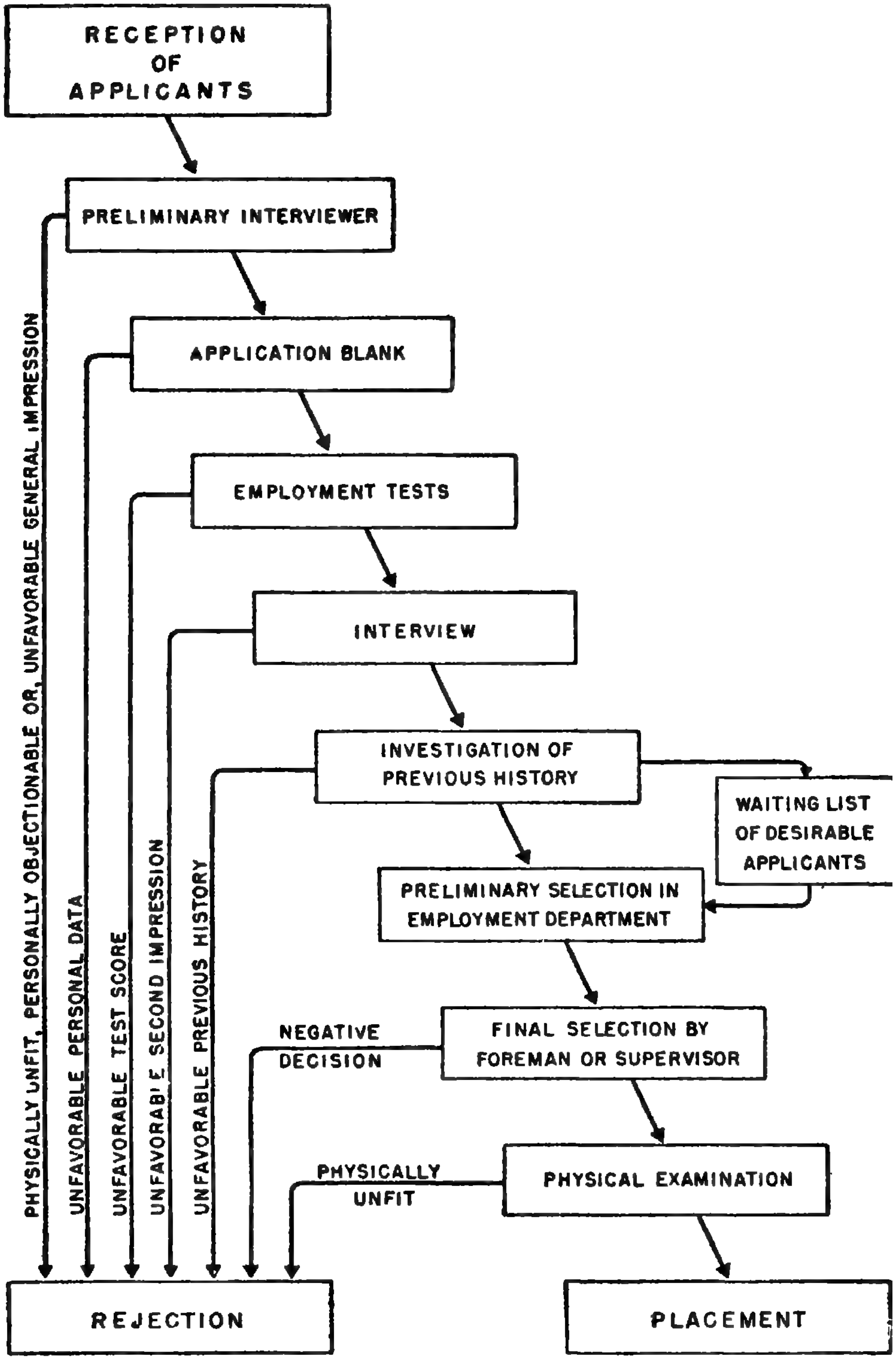
3.3.2 Application forms. A carefully devised application form is in itself an effective selective device. For this reason, application forms are specially designed for each principal class of job to be filled. For positions requiring special skills, detailed questions on appropriate experience and training are asked. If a single application form is used for all applicants, it can at best provide only "face-sheet" information, identifying the individual and providing a few general facts about his background and experience.

3.3.2.1 Weighted or predictive application blanks. If large numbers of persons are to be employed for similar or identical positions, weighted application blanks may be prepared. These include many definitive items that have a demonstrated relationship to success on the job. Since special predictive forms require extensive research, they are expensive to prepare. Such expense is justified, however, if large numbers are to be selected, for the application form may greatly reduce the number of additional selective devices required.*

3.3.3 Preliminary employment interview. The preliminary employment interview seeks to discover answers to the most important and definitive questions about the job or jobs to be filled. It is distinctly directive. The process has been outlined as follows:

"The preliminary interview is distinctive, as compared with other interviews used in the selection process, in that it is shallow and is closely directed by the interviewer. It does not ordinarily

* For an example of such a form and a discussion of the procedure employed in preparing it, see Albert K. Kurtz, "The Weighted Application Blank," *Management Record*, Vol. 10, No. 1, January 1948, 2-4; Josephine Welch and C. Harold Stone, "How To Develop a Weighted Application Blank," *Technical Report No. 11*, University of Minnesota Industrial Relations Center, 1951.



Reproduced by permission from R. S. Uhrbrock, "Mental Alertness Tests as Aids in Selecting Employees, *Personnel*, Vol. 12, May, 1936, 231.

FIG. **4.13** FLOW-CHART OF SELECTION PROCEDURE.

probe deeply into the applicant's special qualifications, interests, and experience. On the contrary, the interviewer seeks to move rapidly from one indicator to the next, checking them off until one of them eliminates the candidate or he is cleared for further investigation. The interview may begin with a question as to the applicant's place of residence. If that hurdle is passed, age may be the next. Educational accomplishments may be the basis for a third question

and experience a fourth. 'Are you married?' may give the answer to a fifth indicator. Thus, the preliminary interview is generally brief and distinctly 'directive' in the sense that it is controlled to cover major questions that concern the interviewer.

"Throughout the whole selection procedure, careful records are preserved to provide a basis for checking and improving the selection program. Such records are essential to analysis and perfection of the procedure.

"In addition, of course, these records may be highly important in indicating the volume and nature of work performed in selection, and in demonstrating compliance with legal regulations affecting employment. The work of interviewers should be summarized and included in the regular reports of the personnel or industrial relations department. For that purpose, notations and records of each interview should be maintained." *

3.3.4 References. A request for references is commonly included in the application form. Available evidence indicates, however, that no actual use of these references is made in most current practice. And much of the use that is made is ineffective because the confidential nature of such inquiries is not assured. If any dependence is to be placed on statements secured from references, special care must be used in soliciting information and assuring its secrecy.

3.3.5 Determinative interviews. In much current practice, principal dependence is placed on determinative interviews. These conferences are reserved for applicants who have passed through the preliminary stages of selection procedure and are believed to have sufficient promise to justify further consideration.

Unplanned, casual interviews at this stage involve many hazards and are likely to be misleading and unreliable. They give only a general impression, which may be conditioned by a "halo" effect induced by the prejudice of the interviewer or by a single trait of the interviewee. For this reason, recent practice has turned to much more carefully planned or "patterned" interviews, carefully designed and conducted to bring out a variety of characteristics. Outlines or guides are available to assist in these patterned employment interviews. Figure 4.14 is an excerpt from a patterned interview form.* Hoveland and Wonderlic's Diagnostic Interviewer's Guide, another of these devices, is illustrated in Fig. 4.15. Other aids are available in the form of special interviewers' rating scales.

3.3.6 Employment testing. Use of tests in selection is now well established in practice. Standardized tests available for this purpose have increased in number, and experience has demonstrated that they can be helpful in supplementing interviews and other devices used in selection. Properly administered and interpreted, they are time-savers and help improve the accuracy of predicting success on the job.

3.3.6.1 Types of tests. Tests used in selection are of seven principal types, as follows:

1. *Performance tests,* which indicate what the individual can do on specific tasks. These are tests of achievement and proficiency, such as typing or shorthand tests, or tests that appraise the applicant's skill in operating an adding or calculating machine.

2. *Trade tests,* which are used to discover and measure the applicant's trade knowledge and skill. These are closely related to performance tests, and some of them actually involve the performance of simple operations requiring specialized skill.

3. *Intelligence tests,* which appraise intelligence or mental alertness. Such

* Quoted from Yoder, *Personnel Principles and Policies,* pp. 148-149.

* For additional information on such interviews, see Carl Iver Hoveland and E. F. Wonderlic, "Prediction of Industrial Success from a Standardized Interview," *Journal of Applied Psychology,* Vol. 23, No. 5 October 1939, 537-546.

ROBERT N. McMURRY & CO.
332 S. Michigan Avenue
Chicago 4, Illinois

PATTERNED INTERVIEW FORM

Date________________________19____

S U M M A R Y

Rating 1 2 3 4 Comments ________________________________
IN MAKING FINAL RATING BE SURE TO CONSIDER APPLICANT'S STABILITY, INDUSTRY, PERSEVERANCE, LOYALTY, ABILITY TO
____
GET ALONG WITH OTHERS, SELF RELIANCE, LEADERSHIP, MATURITY, MOTIVATION; ALSO DOMESTIC SITUATION AND HEALTH.
____
____
____

Interviewer ________________ Job considered for ________________

Name________________Sex M____F____Telephone No.________
IS THIS HIS OWN PHONE OR SOMEONE ELSE'S?

Present address________________City________________State________
IS THIS A DESIRABLE NEIGHBORHOOD? TOO HIGH CLASS? TOO CHEAP?

Date of birth________________Soc. Sec. No.________________

Do you own a car? Yes____No____Make________Age________Condition of car________
WILL HE BE ABLE TO USE HIS CAR IF NECESSARY?

Military Service Status ________________________________
WERE ANYTHING UNDESIRABLE HERE?

Why are you applying for work in this Company?________________
IS HIS UNDERLYING REASON A DESIRE FOR PRESTIGE, SECURITY OR EARNINGS?

WORK EXPERIENCE. Cover all positions. This information is very important. Interviewer should record last position first. Every month since leaving school should be accounted for. Note military service in work record in continuity with jobs held since that time. Experience in Armed Forces should be covered on supplemental form.

LAST OR PRESENT POSITION

Company________________City________________From________19____To________19____
DO THESE DATES CHECK WITH HIS APPLICATION?

How was job obtained?________________Superior________________Title________
HAS HE SHOWN SELF-RELIANCE IN GETTING HIS JOBS?

Nature of work at start________________Starting salary________
WILL HIS PREVIOUS EXPERIENCE BE HELPFUL ON THIS JOB?

Were promotions obtained or raises in pay received?________________
HAS HE MADE GOOD WORK PROGRESS?

Nature of work at leaving________________Salary at leaving________
ANY SUPERVISORY POSITIONS? ANY INDICATION OF AMBITION?

Was there anything you specially liked about the job?________________
HAS HE BEEN HAPPY AND CONTENT IN HIS WORK?

Was there anything you specially disliked?________________
WERE HIS DISLIKES JUSTIFIED?

How much time have you lost from work?________Reasons________
IS HE RELATIVELY HEALTHY?

Reasons for leaving________________________________
ARE HIS REASONS FOR LEAVING REASONABLE AND CONSISTENT?

Part time jobs________________________________
WILL THIS INTERFERE WITH THE JOB UNDER CONSIDERATION?

NEXT TO LAST POSITION

Company________________City________________From________19____To________19____
DO THESE DATES CHECK WITH HIS APPLICATION?

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FIG. **4.14** EXCERPTS FROM THE MC MURRY PATTERNED INTERVIEW FORM.

tests are designed to measure memory, ability to reason, to think, to comprehend, and in some cases to measure "social intelligence," the ability to get along and cooperate with others.

4. *Aptitude tests,* which seek to measure potential abilities and capacities—for example, mechanical or musical aptitudes.

5. *Interest tests,* which are designed to discover patterns of interest and thus to suggest what types of work assign-

DIAGNOSTIC INTERVIEWER'S GUIDE

NAME____________________ DATE____________

ADDRESS____________________ INTERVIEWER____________

The interviewer should begin each interview with this statement to himself, "This applicant will impress me according to my past experience with persons who remind me of him. Consequently I must be on my guard against such prejudices which may naturally arise on account of this. I must keep a record of the fact and judge the applicant on the basis of the facts only. The applicant is a blank to me now." (Interviewer should write out information received as answers to the questions in the space left for that purpose.) If extra space is needed use separate sheets of paper All of this material should be included with the blank itself when returned to the personnel department. The questions which are listed below for the interviewer to ask the applicant are suggestive Other queries pertinent to the applicant's history will naturally suggest themselves to the interviewer as he contacts the applicant.

Please read special instructions on last page before interviewing.

WORK HISTORY

Interviewer says—

1 "Give me the names of your past employers Begin with the last or present employer and go backward Tell me:
   (a) How you got the job.
   (b) What you did, and,
   (c) Why you left.

2. How did your previous employers treat you?

3. What experience of value did you get from each job?

4. Did you do work of such quality that your employer would be glad to recommend you?

5. Were you ever criticized for the kind of work you did? Give me some examples of mistakes or failures.

6. Can you give me any example of success in your experience, particularly in handling people?

7. What kind of work did you enjoy the most and seem to progress the best in?—
   (a) Mechanical work?
   (b) Clerical and detail work?
   (c) Contact work?
   or (d) Do you know?

When the interviewer has secured as much information as it is possible for him to get concerning every phase of the applicant's work history, he should ask himself the following questions:

1. What kind of work history does the applicant have?
   (—) Poor — Fair | Good — Excellent (+)
2. Has it been the type of work which has required meeting and handling different types of people? (+) Yes | No (—).
3. Has the applicant indicated ability to work consistently? (+) Yes | No (—).
4. Has the applicant indicated a serious and sincere attitude toward the work he has been doing? (+) Yes | No (—)
5. Has the work been such as to necessitate the development of habits of persistence and aggressiveness? (+) Yes | No (—).
6. Has the work history indicated a capacity for growth? (+) Yes | No (—).
7. Does the work history reveal habits or attitudes which would make it easy for the applicant to adjust himself to the policies and procedures of this company? (+) Yes | No (—).
8. Is this man a good soldier as evidenced by good team-work? (+) Yes | No (—).

Reproduced by permission from E. F. Wonderlic, Glencoe, Illinois.

FIG. **4.15** EXCERPT FROM THE DIAGNOSTIC INTERVIEWER'S GUIDE.

ment may be appropriate and satisfying.

6. *Tests of emotional reactions and adjustment,* which indicate the emotional stability of the candidate and appraise his characteristic mood and over-all attitude toward his status and associations.

7. *Tests of attitudes,* which are designed to get at the point of view and "mind set" of the individual, to discover how he feels about the values regarded as important by those who operate the selection program. Added attention is given to such analysis in the later dis-

cussion of employee morale (Art. 5.2). Attitude studies are frequently used to appraise the morale of present employees as well as of applicants.

3.3.6.2 Testing principles. Careless use of tests and the application of poorly designed tests have done much to discredit testing as a means of selection. In general, the following principles should be observed:

1. Testing should supplement, not substitute for, other selection procedure. In even the most elaborate testing programs, such as those developed during World War II for the Air Forces and the Office of Strategic Services, testing is only part of the total selection procedure.

2. The administration of most tests must be standardized. Where tests are given under a variety of conditions, great variation in test scores may occur.

3. Tests must be tested. Only a few of the simpler performance tests give a direct indication of success on the job. Tests of typing speed and errors, for example, have a fairly clear meaning. But for more complicated tests, it cannot be assumed that a high test score means a satisfactory employee. On the contrary, for many jobs high scores on certain tests should probably be regarded as definite warnings against employment. The test to use is the test that works, which means that results must be analyzed and related to job performance to discover how well each test works.

4. Testing, except in the simplest programs, should be conducted by a person who has had training in test construction, administration, and analysis. Although such training need not be lengthy and may provide only a general understanding of testing theory and practice, it should ensure the care and understanding that are essential to the proper use of tests.

5. Since testing programs can be made more useful by additional research, all studies of testing programs should be reported in current professional journals. Those in charge of testing in industry and government have an obligation to conduct such studies and to report their results to others in the professional field.

6. Distribution of testing materials must be carefully controlled. Misuse of tests by persons who are not familiar with their purposes and limitations may seriously affect the interests of those tested and may also create misunderstanding of the whole testing procedure. If tests fall into the hands of people who are later to be tested, the meaning and validity of the test results may be distorted. For these reasons, sample tests cannot be broadcast.

7. Those who administer the testing program should interpret the results to all who are to make use of them. Test scores are not as simple to analyze as the grades on a grammar-school arithmetic problem. In some cases, the correlation between test scores and job performance is negative. So a high score may mean less probability of success. Scores may be percentiles; they may be "raw"; they may be based on "norms" calculated for high-school or college students or for other distinctive groups. Some of them can be described only in terms of patterns or profiles. Obviously, careful interpretation of scores to all who are to use them is essential.

3.3.6.3 Limitations of testing. Robert N. McMurry has provided an excellent summary of the limitations of testing in selection. He points out that all tests must be validated before they can be used with confidence. In other words, it must be shown that they do what they are supposed to do. It cannot be assumed that because a given test has worked satisfactorily in selection for one job it will be similarly satisfactory for another. Nor is it enough that the test has reliability—that repeated administrations give essentially the same results. Nor can it be assumed that the test will work simply because it appears logically related to job performance. McMurry says:

"*. . . It is not generally recognized that even under the best of circumstances there is a definite limit to the efficiency of a single test or a battery*

of tests. Actually, the validity obtained in industry for a given test, or battery of tests, rarely reaches .70. This figure indicates the magnitude of the 'coefficient of correlation' between performance on the test and job success. It does *not* indicate the *percentage* of efficiency of prediction produced by the test or tests. (This coefficient is an arbitrary index, designed to indicate the closeness of the relationship between these two variables: performance on the tests and job success. A coefficient of 1.00 indicates complete correspondence; a coefficient of −1.00 indicates complete negative correspondence; and a coefficient of 0 indicates no agreement whatever.) The variations in the degree of correspondence can best be seen from the following table:

Coefficient of correlation	Index of predictive efficiency
.10	.5%
.20	2.
.30	5.
.40	8.
.50	13.
.60	20.
.70	29.
.80	40.
.90	56.
1.00	100.

As may be seen, a small coefficient of correlation does not greatly increase the efficiency of prediction (a coefficient of .10 increases it by but one-half per cent; of .30, by but 5 per cent; and of .50, by but 13 per cent). A validity coefficient of .68, taking any case at random from the distribution as a whole, will improve the efficiency of prediction by but 28 per cent. In short, tests at best merely reduce the error of prediction; they never eliminate it entirely.

"Where there is a well-established correlation between a test and a criterion and the relation is 'linear,' good results can be obtained, even though the correlation is relatively low, if the critical (passing) score is set sufficiently high. Thus, the efficiency of prediction can be increased very appreciably. The final contribution of any testing program is a function not only of the magnitude of the validity coefficient, but also (1) of the per cent of the total number of applicants who must be selected and (2) the ratio of the individual effectiveness of those selected to those rejected. The total dispersion of the distribution gives only a very poor index and does not take into account at all the greater efficiency arrived at when skimming the cream off the top of a distribution.

"On the other hand, this increase in predictive efficiency is often obtained at considerable cost from a practical employment point of view. This is because if the critical score is set so high that most of those who pass are almost certain to be successful, it is inevitable that many others will be rejected among whom are some *who would also be successful.* If the labor supply is ample and the employer is willing to spend the time and effort to test enough men to get the required number of high-scoring applicants, such a procedure will be very rewarding. (It was especially well suited to the armed forces where many men are available and testing facilities were ample.) In industry, on the other hand, particularly in today's labor market, it is not always economical to lose potentially desirable employees in order to increase the certainty of the success of those who meet high test standards.

"The employer is faced with these alternatives: either to set employment test standards relatively low, with a corresponding loss of predictive efficiency, that is, with an increase in the proportion of those hired who do poorly on the job, or to set them high with a corresponding loss of qualified applicants. This means that those advocates of tests who claim to be able to increase the efficiency of prediction by as much as 85 per cent, do so at the risk of the loss of numerous potentially desirable candidates. In actual practice, the instances in which *any* battery of tests with *any* standards will improve the efficiency of prediction by 85 per cent are so rare that such claims can usually

be taken as an evidence of charlatanism on the part of their makers." *

3.3.6.4 Test construction. Building tests is a very complicated and specialized function. Valid, reliable tests are not likely to result from haphazard test construction. Clifford E. Jurgensen gives this word of caution:

"*Anyone can develop a test.* Although the basic principles of testing are age-old and are simple, it must not be thought that the development and administration of a test program is a routine matter which can be entrusted to any available clerk. An analogy can be drawn in the field of X-ray therapy. The procedures for handling X-ray machines may appear simple to an onlooker, and actually *are* simple in the hands of an expert, but the machine can cause much damage, even death, when the 'simple' procedures are followed by an untrained person. Likewise, tests can cause much harm when handled incorrectly. Cases are known where tests have actually resulted in rejecting the best applicants and hiring the worst! Use of incorrect procedures can also upset employees from the viewpoint of union-management relations, and can also adversely affect the attitudes and morale of individual employees.

"Tests sometimes appear so simple that some persons believe test construction requires nothing other than the ability to 'think up' 50 or 100 questions and then have them printed as a test. Although there are many fallacies in this type of procedure, only one will be given here. As mentioned previously, a test is a sample of behavior, and the assumption is made that the test is a representative sample of the whole. For purpose of illustration, let us suppose that two persons are to be tested for arithmetical ability, and that each of three persons has constructed a 'home made' test of arithmetical ability. Let us further suppose that the ability of the two persons to be tested is equal. It can be possible that test constructor *A* will make a test which contains items all of which can be answered correctly by the first person and none of which can be answered by the second person; and constructor *B* will make a test on which the first person can answer none of the items and the second person can answer all of the items. Obviously, use of either test would result in one perfect score and one zero score, but the position of the two persons being tested would be reversed! Such an extreme is not likely to occur in actual practice, but strong tendencies along this line frequently occur in tests which are constructed by untrained persons. Many pitfalls such as the sampling error just discussed must be taken into consideration by test constructors. Only a person with sound basic training in test construction knows what they are and how to overcome them. Although an occasional excellent test may be constructed by an untrained person, the odds are small for a good test but large for valueless or even dangerous results." *

3.4 PLACEMENT AND INDUCTION

The new employee must be shown to his job, introduced to his fellow-employees and supervisor, and assisted in making such personal adjustments as are necessary to his effective performance in the work team. Current practice provides a program of placement, induction, preliminary counseling, and orientation for new employees. If the numbers of new employees are large, the program may involve special orientation sessions. It may include a plant tour. The new employee may be given a handbook that describes the employer, principal products, and rules, regulations, and privileges affecting employees. A present employee may be designated

* Reproduced by permission from Robert N. McMurry, "How Efficient Are Your Hiring Methods?" *Personnel Journal*, Vol. 26, No. 2, June 1947, 45-53.

* Reprinted by permission from Clifford E. Jurgensen, "Common Misconception Toward Personnel Test," *GAS*, Vol. 24, No. 8, August 1948, 31-34.

as sponsor for the new employee to help him become acquainted with working conditions.

3.5 TRAINING

Both new and old employees may require training. From the very beginning of their employment, training may be necessary to prepare them for the special tasks and responsibilities assigned to them. Training is a responsibility of the operating line. But the technical operation—the planning and direction of training—is generally delegated to staff personnel in the training division. Training is planned on the basis of information provided by job analysis. It may be carried on entirely on an in-plant basis, or it may involve cooperative arrangements with local high schools, technical and vocational schools, and colleges and universities.

3.5.1 Types of training. A wide range of training programs has proved useful in various types of employment. A partial list includes job training, vestibule training, craft training, professional training for staff positions, apprenticeship training, supervisory training, steward training, executive training, Americanization courses, induction and orientation training, safety training, sales, service, and office training, citizenship training, and many others.* A basic outline for a training coordinators' institute, prepared by the Northern Ohio Chapter of the American Society of Training Directors,† lists eleven areas for program coverage: induction, vestibule, on-the-job, spot, presupervisory, supervisory, job-instruction training, job-relations training, job-methods training, and technical and special group programs.

The scope of training is governed by the major types of employees who are to be trained. Five distinctive groups of employees may be noted: rank and file, supervisory, staff, middle management, and top management. Rank-and-file employees have no administrative or supervisory duties. Supervisory employees include first-line foremen and supervisors and their immediate superiors. Staff is composed of specialized technical and professional persons attached to the operating line to provide counsel and aid Middle management is made up of those holding positions between these first-line supervisors and top management. Although the lines of demarcation are not sharp, middle-management positions include general foremen, shop superintendents, minor executives, and assistants to top management. Top management is made up of executives who hold major responsibility for over-all planning and control of the entire operation.

On the basis of these distinctions, the various types of training can be outlined as on p. 224.

3.5.1.1 Job training. The most common type of in-plant training is job training. Actual training in job performance is generally undertaken either on the job or in "vestibule" schools, depending principally on the number of trainees to be instructed at any particular time. Training on the job is generally preferred in smaller plants. The trainee is placed in the shop, generally under the guidance and sponsorship of one or more experienced employees, and is allowed to learn the job by doing it. Experience thus gained may be supplemented by outside lectures or demonstrations. Some programs provide written manuals or instruction books.

In the vestibule school, a class of trainees is given a planned course of instruction and practice under circumstances that simulate those of the shop. Instructors who have no responsibility for immediate production devote their full time to training. The vestibule school

* See also "Basic Training Policies," *Industrial Relations Digests No. 6*, Industrial Relations Section, Princeton University, April 1941; also "Problems of Reemployment and Retraining of Manpower During the Transition from War to Peace: A Selected, Annotated Bibliography," Industrial Relations Section, Princeton University, March 1945.

† Cleveland (400 Union Commerce Building) 1951.

In-plant training programs

1. Rank and file:	Induction and orientation Job training Craft training-apprenticeship Steward training Safety Sales, service, and office Special purpose
2. Supervisory:	Supervisory induction Foremanship Safety Manpower management
3. Staff:	Professional Technical
4. Middle management:	Management induction Executive training
5. Top management:	Training in executive development

has the advantages of specialized, superior instruction, absence of pressure to get out production, the possibility of frequent lectures or discussions, and greater personal attention to each trainee. In many cases, the period of instruction can be shortened. Waste and spoilage, often an important source of expense in on-the-job training, can be reduced.

Both systems of job training are widely used. Some firms use a combination of the two, in which preliminary training is provided in vestibule schools, followed by on-the-job training in the shop. Surveys of current practice indicate that such combinations are more common than either on-the-job or vestibule schools alone.

3.5.1.2 Apprentice training. In the oldest of these training-in-employment programs, craftsmen are trained under apprenticeship arrangements, many of which were developed before the Industrial Revolution. Training of craftsmen depends in large measure on day-to-day practice under the supervision of skilled journeymen. Today, however, this practice is combined with classroom training designed to improve on-the-job instruction and to shorten the learning period. For more than 50 crafts, such apprenticeship arrangements are the established and accepted training procedure. In many of them, training is arranged under contract—that is, it is "indentured" under an agreement that specifies how long the apprentice will spend in securing instruction and who will provide such training. The agreement also insures progressively increasing wage rates throughout the apprenticeship period.

Federal and state apprentice-training agencies (in some 30 states) now outline standards for acceptable apprenticeship programs, and cooperate with employers and unions in developing and maintaining them. They encourage indentured apprentice-training programs. They enforce accepted standards, including a minimum age (16 years), minimum and maximum lengths of training periods (2,000 to 10,000 working hours), group instruction under public authorities (at least 144 hours per year), and minimum wages (beginning at not less than 50 per cent of journeyman rates). These public agencies encourage the creation of joint employer-employee apprentice-training committees for the various crafts. More than 5,000 of these committees are now functioning throughout the country.*

3.5.1.3 Supervisory training. Another common type of training is supervisory training. Table 4.6 outlines the content of one carefully planned supervisory training program.

3.5.2 Principles of training. Whatever

* For greater detail, see Paul Bergevin, *Industrial Apprenticeship* (New York: McGraw-Hill Book Company, Inc., 1947). Also *Setting Up an Apprenticeship Program* (Washington, D. C.: U. S. Department of Labor Apprentice Training Service, 1946).

TABLE 4.6 CONTENT OF SUPERVISORY TRAINING PROGRAM*

Administrative training	*Orientation training*	*Human relations training*	*Technical training*	*Teacher training*
1. Duties and responsibilities of a supervisor	1. The company size, organisation, history, markets	1. Building production incentives	1. Basic science and mathematics	1. Instructor training
2. Principles of industrial organization	2. Product training	2. Inducting new employees	2. Special technical training—rubber, chemistry, textiles, traffic management, sales, design, etc.	2. Conference leadership
3. Controlling	3. Shop rules and regulations	3. Giving orders and directions	3. Trade training	
	4. Personnel policies (leave, vacation, payment, promotion, etc.)	4. Developing understudies	4. Costs	
	5. Union contract	5. Correcting and improving subordinates	5. Job evaluation	
	6. Company services (hospital, nurse, recreation, housing, training classes, transportation, cafeteria, welfare)	6. Building initiative and confidence	6. Methods	
	7. Service departments (Costs, Methods, Production Control, Personnel, Purchasing, Quality Control)	7. Placement and supervision of veterans	7. Time study	
		8. Placement and supervision of women	8. Production control	
		9. Measuring production incentives	9. Labor legislation	
		10. Reducing absenteeism and labor turnover		
		11. Self-improvement		

* From Earl Planty and William McCord, "The Scope and Organisation of Supervisor Training," *Personnel*, Vol. 22, No. 4, January 1946, 224.

the type of training, it should be based on the following generally recognized principles:

1. Training must always recognize individual differences—differences in ability, interest, learning speed, and other significant personal characteristics.

2. Training should reflect the information provided by job analysis, which indicates both the need for training and the nature of the training to be provided.

3. Incentives are always important in training. Motivation of trainees cannot be taken for granted.

4. Participation of executives and supervisors, as well as trainees, in training activities is an important means of enhancing motivation and interest in training.

5. Teachers must be carefully selected and must themselves be given special training if necessary.

3.5.3 Training methods. Among the principal methods of employment training are the following:

- On-the-job instruction
- Apprenticeships
- Lectures
- Conferences and projects
- Role-playing
- Position rotation
- Understudy programs
- Internships
- Scholarships and fellowships for attendance in puplic or private educational institutions*

* For detailed discussions of each of these methods, see Yoder, *Personnel Principles and Policies,* pp. 239-251; William W. Mussman and Wilbur M. McFeely, "Techniques of Conference Leadership," National Industrial Conference Board Reports, *Studies in Personnel Policy No. 77,* 1946; Edward S. Maclin and Paul T. McHenry, *Conference Leader Training* (Deep River, Conn.: National Foremen's Institute, 1945); Kenneth B. Haas and Claude H. Ewing, *Tested Training Techniques* (New York: Prentice-Hall, Inc., 1950); Leland P. Bradford and Ronald Lippitt, "Role-Playing in Supervisory Training," *Personnel,* Vol. 22, No. 5, March 1946, 358-369; Alex Bavelas, "Role Playing and Management Training," *Personnel,* Vol. 24, No. 8, May 1946, 11-16; Elwood N. Chapman, "Role Playing in Cooperative Retail Training Class," *Occupations,* Vol. 29, No. 5, February 1951, 358-359; Chris Argyris, "Role-Playing in Action," *Bulletin No. 16,* New York State School of Labor and Industrial Relations, May 1951; A. A. Liveright, "Role-Playing in Leadership Training," *Personnel Journal,* Vol. 29, No. 11 April 1951, 412-416.

3.6 PERSONNEL RATING

Individual employees may be rated for a variety of purposes. Perhaps the most frequent purpose is to provide a measure of demonstrated and potential abilities as a basis for adjusting compensation. Ratings are also used to identify employees who appear promising candidates for promotion.

It is often said that ratings are used to measure personal characteristics for which there are no real measures. The point is that no objective measures of such personal traits as honesty, dependability, and initiative exist, but that an estimate or judgment of these qualities is made available in personnel ratings.

Rating is designated by a variety of terms. It is called "efficiency," "proficiency," "merit," "performance," "service," and "personnel" rating. None of these designations has achieved general acceptance. "Personnel rating," however, has the advantage of suggesting that it is people who are being rated. It thus distinguishes the process from the rating of jobs in job evaluation, the rating of plant experience in workmen's compensation rating, and the rating of employment experience in unemployment compensation.

3.6.1 Types of personnel rating. The most common rating procedure is the appraisal of employees by their supervisors. This is known as *vertical* rating. When fellow-employees provide the evaluations, the procedure is known as *horizontal* rating or *mutual* rating. Sometimes employees are asked to provide *self-ratings*.

3.6.2 Rating scales. Rating procedure generally uses a form called a *rating scale,* on which the rater records his impressions of the ratee. Most commonly used is a listing of the qualities to be

FCA 7-6

EMPLOYEE APPRAISAL

Employee's Name ______________________ Classification ______________

Bank ______________ Department ______________ Division ______________

Rating Supervisor ______________________ Section ______________

This form is designed to help you appraise accurately the value of employees to the organization. You are asked to rate the employee on each of the several traits or qualities listed here. After each trait there is a line representing various degrees of the trait. The descriptive phrases beneath the line indicate the amounts or degrees of the trait represented by five points along the line. They are guide-posts. You rate the employee by checking at any place along the line that represents your judgement of him.

In view of the importance of these ratings, you are asked to study and observe the rules printed on the other side of the sheet.

QUALITY OF WORK	Doubtful that quality is satisfactory.	While not unsatisfactory, quality is not quite up to standard.	Quality is quite satisfactory.	Quality of work is superior to that of general run of empoyees.	Exceptionally high quality.	No chance to observe. ______
VOLUME OF WORK	Unusually high output.	Turns out more work than general run of comparable employees	Average, satisfactory output.	Inclined to be slow.	Insufficient out put.	No chance to observe. ______
CAPACITY TO DEVELOP	Future growth doubtful.	Moderate development ahead.	Shows promise	Very promising promotional material.	Great future growth probable; should go far	No chance to observe. ______

FIG. 4.16 PORTION OF SIMPLE PERSONNEL RATING SCALE USING DESCRIPTIVE PHRASES.

CLASSIFICATION SYMBOLS		
SERVICE	GRADE	CLASS

GRAPHIC RATING SCALE

(SEE INSTRUCTIONS ON REVERSE SIDE OF SHEET)

Efficiency Rating Form No 8

NON-SUPERVISORY ________ ☐

SUPERVISORY ________ ☐ (CHECK ONE)

NAME ________ (Surname) ________ (Given name) ________ (Initial) DEPARTMENT ________

________ (Bureau) ________ (Division) ________ (Section) ________ (Subsection)

ELEMENT NUMBER	SERVICE ELEMENTS	NOTE MARK ONLY ON ELEMENTS CHECKED IN LEFT-HAND MARGIN					DO NOT USE SPACE BELOW
☐ 1	Consider accuracy, ability to produce work free from error, ability to detect errors	Highest possible accuracy	Very careful	Careful No more than reasonable time required for revision	Careless Time required for revision greatly excessive	Practically worthless work	
☐ 2	Consider reliability in the execution of assigned tasks, dependability in following instructions; accuracy of any parts of product appraisable in terms of accuracy	Greatest possible reliability	Very reliable	Reliable	Doubtful reliability	Unreliable	
☐ 3	Consider neatness and orderliness of work.	Greatest possible neatness and orderliness	Very neat and orderly	Neat and orderly	Disorderly	Slovenly	
☐ 4	Consider the speed or rapidity with which work is accomplished, the quantity of work produced in a given time; the dispatch with which a task of known difficulty is completed.	Greatest possible rapidity	Very rapid	Good speed	Slow	Hopelessly slow	
☐ 5	Consider industry, diligence, attentiveness, energy and application to duties; the degree to which the employee really concentrates on the work at hand.	Greatest possible diligence	Very diligent	Industrious	Inattentive to work	Lazy	
☐ 6	Consider knowledge of work, present knowledge of job and of work related to it; specialized knowledge in his particular field.	Completely informed	Unusually well informed	Well informed	Poorly informed	Lacking	
☐ 7	Consider judgement, ability to grasp a situation and draw correct conclusions, ability to profit by experience, sense of proportion or relative values, common sense	Perfect judgment	Excellent judgment	Good judgment	Poor judgment	Neglects and misinterprets the facts	

FIG. 4.17 PORTION OF PERSONNEL RATING SCALE PROVIDING SHORT DEFINITIONS OF TERMS.

rated, with questions or a linear scale on which the rater indicates the degree of each quality. Scales are illustrated in Figs. 4.16 and 4.17.*

3.6.3 Principal deficiencies. Caution is essential in the use of ratings. The fact that they provide an approximate evaluation for qualities that cannot be objectively measured suggests the likelihood of errors in the rating process. John C. Flanagan has described five principal shortcomings in personnel ratings:

1. Failure to obtain a "spread" of scores. This is sometimes described as "central tendency," meaning that raters tend to show all ratees as about average with respect to the qualities rated. But, as Flanagan notes, they may also tend to rate all ratees too high or too low.

2. The "halo" effect, in which the rater's general impression of the individual or of one quality influences his appraisal of each individual trait.

3. Varying standards applied by various raters. This tendency is particularly noticeable and troublesome when two divisions are to be compared, or when ratings from several units are to be combined.

4. Unreliability of ratings, by which is meant a lack of consistency. If ratings are unreliable, the scores given to the same group of ratees by two raters may form no consistent pattern. Those who rank at the top with one rater may fall into lower ranks in another rater's evaluation. In such a situation, little reliability can be attached to the scores.

5. Lack of validity, which means that the ratings given do not accurately measure the qualities rated. Such discrepancies can be demonstrated only if ratings appraise some qualities for which other objective measures are available. For example, if ratings on productivity assess out-put inaccurately, they are not valid.†

One of the major problems in rating is finding raters who know ratees well enough to do a good job. In many cases, errors in ratings reflect the raters' unwillingness to commit themselves on points about which they do not feel sure. As a result, ratings may reflect what is generally described as "leniency."

3.6.4 Rating errors. Individual differences in the standards that raters apply to ratees result in varying ratings being given to identical ratees by two or more raters. By analyzing these differences, it is possible to evaluate the rating tendencies of raters. Thus, if a rater tends to rate all ratees higher than other raters do, this tendency can be noted and measured. If the tendency is consistent, the rater's ratings can be "corrected" accordingly.

To discover such tendencies, ratings are frequently analyzed in terms of systematic and total errors. Systematic errors are calculated by comparing the scores given by a particular rater with the average of scores on the same ratee or trait given by all raters. The differences, plus or minus, are totaled, and the result indicates the rater's tendency to score high or low. Total errors are calculated in a similar manner, except that the differences are totaled without regard to plus or minus signs.

Systematic errors measure a particular rater's severity or leniency and indicate how his ratings should be discounted or adjusted. Total errors merely indicate the tendency of the individual rater to vary from other raters. They thus suggest how much reliance may be placed on the rater's scores, on the assumption that the average of all raters' scores is a satisfactory criterion.

4. WAGE AND SALARY ADMINISTRATION

Wage and salary administration is one of the major responsibilities of modern manpower management It is,

* For additional detail, see M. Joseph Dooher and Vivienne Marquis, eds., *Rating Employee and Supervisory Performance* (New York: American Management Association, 1950).

† From John C. Flanagan, "A New Approach to Evaluating Personnel," *Personnel,* Vol. 26, No. 1, July 1949, 35-42. See also Marion W. Richardson, "Forced-Choice Performance Reports," *Personnel,* Vol. 26, No. 3, November 1949, 205-212.

of course, a line responsibility, but continually increasing complications have demanded the attention of specialized staff members. Prospective problems—involving questions of annual wages, guaranteed wages, cost-of-living adjustments, and improvement factors—and numerous highly complicated "fringe" payments all tend to emphasize the need for specialized staff in the wage and salary area.

4.1 TERMINOLOGY

Several of the most widely used terms should be defined to prevent misunderstanding. Among these are:

4.1.1 Wages. The term "wages" is probably the broadest of all designations applied to compensation. In popular usage, it refers to payments for services, whether to manual or white-collar employees, and whether based on hours of employment, output, or some other yardstick. In this usage, the term includes salaries, bonuses, and commissions, as well as board and room and other perquisites. Because this term is used so broadly, its meaning is always obscure.

In a somewhat more restricted and meaningful usage, the term "wages" refers to compensation paid for services of hourly-rated or other nonsupervisory and nonclerical employees. Here the term "employees" refers to several distinctive groups, including managerial and supervisory manpower, salaried white-collar groups, and hourly-rated (generally manual) employees. Hourly-rated employees include those paid on a piece-rate or output basis, because hourly "base rates" are established for these jobs.

4.1.2 Wage rates-time and piece. Whereas the term "wages" generally refers to earnings, "wage rates" are the amounts paid per unit of work performed. There are two principal types of wage rates: time rates and piece rates. *Time rates* are based on time units, most commonly the working hour, although some day rates and weekly rates are used. In its simplest form, the *piece rate* is a flat payment of so much per unit produced. The term includes, in addition to these simple rates, more complicated formulas generally described as incentive wage plans, which are presumed to provide a special incentive for high-level performance. The term "incentive wages" is frequently applied both to simple piece rates and to the more complicated arrangements.

4.1.3 Commissions and bonuses. Commissions represent a common variant of piece rates in which compensation is based on the price or *value* of the services rather than on physical units. Employees are paid a percentage of their sales, for example. Commissions are the established method of compensating for many semiprofessional services, such as those of insurance agents, factory representatives, and outside salesmen. Commissions may also be combined with hourly wages in paying inside salesmen and other employees.

Bonuses are *extra* payments made in addition to usual compensation. They are of two principal types. The first type of bonus is a regularly scheduled reward or incentive granted for extra performance and recognized as an established part of total compensation. Such are the usual "production" bonuses provided for hourly-rated employees as well as for salesmen and executives. A second type of bonus is illustrated by the Christmas or year-end bonus, distributed if and when net earnings justify. It is a gratuity and a source of income on which the employee cannot regularly depend.

4.1.4 Earnings. "Earnings" are the product of wage rates and employment. An employee earns an amount that varies with his rate of compensation and his period of employment or his output.

The most commonly used measure for hourly-rated personnel is *weekly earnings*. The month or year is a more frequent time period for salaried employees. Weekly earnings may reflect the influence of several factors. For example, overtime employment at premium rates is included. So are premiums or bonuses earned by high-level output under vari-

ous incentive plans. Published figures on weekly earnings in manufacturing include these items.* Similarly, they reflect part-time employment.

Hourly earnings for hourly-rated employees may not be the same as wage rates, since they may reflect the influence of overtime at premium rates or of special bonuses. Published rates are averages of hourly earnings. Sometimes, in order to facilitate comparisons from time to time or from one industry to another, refined figures are calculated for *average, straight-time hourly earnings* (ASTHE).

4.1.5 Take-home pay. "Take-home pay" represents the actual amount paid after what many employees refer to as the "deducts." "Deducts" are deductions —amounts regularly subtracted from earnings before the check for take-home pay is issued. The most common deductions are federal pay-as-you-go income taxes and old-age pension or social-security taxes. In addition, deductions may be made for union dues and fees, group insurance, private pension and benefit systems, hospitalization, community chest pledges, and other contributions.

4.1.6 Income. An employee's income is usually calculated on a long-term basis —typically a year—and may include many items other than wage income. Many employees receive income from other members of their households. They may have earnings from more than one employer.

4.1.7 Real wages. The term "real wages" refers to the purchasing power of money wages. Real wages represent the actual exchange value of wage rates or of earnings. In the most common usage, in which wage rates or earnings of different periods are compared, real wages reflect an adjustment to changes in the price level.

4.1.8 Labor costs. In many popular discussions of wages, it is assumed that the terms 'wages" and "labor costs" may be used interchangeably, and that any change in wages automatically occasions a similar change in labor costs. Labor costs are related to wage rates or earnings, but they are not the same thing. Only if wages are paid as piece rates will an adjustment in rates presumably affect labor costs in the same manner and amount. Even then, a change in rates may not occasion any similar adjustment in overhead items and costs. Similarly, when output of employees paid by the hour is controlled by the speed of the production line, changes in wage rates may be closely related to changes in direct labor costs. In other situations, wage rates may be changed without changing labor costs or with labor-cost variations unlike those in wage rates.

4.1.9 Fringe items. From the viewpoint of both employers and employees, direct wage payments are only a part of the wage bill. Many important types of compensation for wage-earners do not appear in wage rates. Some of them are not evidenced in compilations of weekly or longer-term earnings. These payments include, for example, employer contributions to insurance premiums, taxes paid by the employer for old-age pensions and for unemployment compensation, and similar employer expenses that provide benefits for employees. More obvious are payments of premium rates for overtime and holidays, and compensation for down time, call-backs, paid vacations, rest and lunch periods, time spent on grievance settlement, board and room allowances, night-shift premiums, pay for holidays not worked, portal-to-portal pay, and severance pay. They are widely described as fringe items. But they may amount to as much as 20 per cent of the direct wage bill. Figure 4.18 illustrates the significance of these fringe payments in current practice. The survey on which the figure is based revealed that fringe payments amounted to 15.4 per cent of wages.

4.2 ADJUSTMENTS AND VARIATIONS

Mention has been made of such extra compensation as bonuses. In addition to bonus payments, other im-

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* Regularly released in the *Monthly Labor Review*.

FIG. **4.18** COSTS OF FRINGE PAYMENTS*

NONWAGE PAYMENTS BY TYPE OF PAYMENT

		As per cent of wages paid for time worked
Total nonwage payments		**15.4%**
1. Legally required payments (employer's share only)		**3.2**
a. Old-Age and Survivors Insurance	1.0%	
b. Unemployment Compensation:		
(1) 0.3% tax to Federal Government	0.3	
(2) State tax (net)	1.1	
c. Workmen's compensation (including estimated cost for self-insured)	0.7	
d. Railroad Retirement Tax, Railroad Unemployment Insurance, Sickness benefits insurance, etc.	0.1	
2. Pension and other agreed-upon payments (employer's share only)		4.5
a. Pension-Plan premiums and pension payments not covered by insurance-type plan	2.2	
b. Life insurance premiums, death benefits, sickness, accident and medical-care insurance premiums, hospitalization insurance, etc.	1.4	
c. Separation or termination pay allowances	0.1	
d. Discounts on goods and services purchased from company by employees	0.5	
e. Miscellaneous payments (free meals, compensation payments in excess of legal requirements, payments to needy employees, tuition refunds, savings and stock purchase plans, etc.)	0.3	
3. Paid rest periods, lunch periods, wash-up time, travel time, clothes-change time, get-ready time, etc.		1.8
4. Payments for time not worked		4.8
a. Paid vacations and bonuses in lieu of vacation	3.2	
b. Payments for holidays not worked	1.5	
c. Payments for State or National Guard duty, jury, witness and voting pay allowances, payments for time lost due to death in family or other personal reasons, etc.	0.1	
5. Payments to union stewards or officials for time spent in settling grievances or in negotiating agreements	less than	0.05
6. Profit-sharing payments		0.3
7. Christmas or other special bonuses, service awards, suggestion awards, etc.		0.7
8. Special wage payments ordered by courts, wage adjustment boards, etc.		0.1

* Reproduced by permission from *The Hidden Payroll: Non-Wage Labor Costs of Doing Business* (Washington, D. C.: Chamber of Commerce of the United States, 1949), p. 13.

portant adjustments in pay plans include:

4.2.1 Sliding scales. In several industries, both in this country and abroad, rates of pay are adjusted in accordance with some predetermined index of prices. All such arrangements may be described as "sliding scales." Most common are adjustments for changing living costs. Other arrangements adjust wage rates to follow an index of wholesale prices or the price of products of the industry.

4.2.2 Escalator clauses. In the most common sliding-scale arrangement, wage rates are varied according to changes in a cost-of-living or consumers' price index. When such arrangements are provided by collective agreement, they are widely described as "escalator clauses." A particular local or national cost-of-living or consumers' price index is accepted as the yardstick, and wage rates are reviewed at specified intervals—most commonly each three or six months. Rates are adjusted upward or downward in an amount approximating the percentage change in the index.*

4.2.3 Improvement factors. In recent

* See "Escalator Wage Adjustments Based on Price of Product," *Monthly Labor Review,* Vol. 73, No. 1, July 1951, 48-49.

years, a number of collective agreements have provided for annual increases based on increasing productivity. They have included what is generally described as an "improvement factor," which represents an effort to assure employees that they will share immediately in increasing productivity.

For all industry and over a long period of years, productivity increases average from 2 to 3 per cent per year. This figure, or some other figure more directly related to a given industry, may be accepted as a bench mark.

4.2.4 Profit-sharing. Profit-sharing arrangements, in which employees receive some of their compensation through participation in the profits of their employer, have had a long history. Although they have never become common, they attract widespread interest whenever industry is prosperous. For example, they were widely discussed in this country in the years following World War II. In this period, a nationwide Council of Profit-Sharing Industries was established.

These plans follow no simple pattern, except that almost all of them are unilaterally established by employers. They vary widely in coverage—many are limited to executives and top-level administrators—and in methods of sharing. In general, they provide for a system of dividing net profits, usually establishing a minimum amount to be set aside for dividends and specifying how any excess shall be divided. Employers frequently regard profit-sharing as an opportunity to take employees into partnership—as "silent" partners. They feel that, as partners, employees will have an added incentive to work hard and eliminate waste. Employee morale may be improved and may stimulate greater output.

Evidence indicates that certain plans have achieved these results. On the other hand, the plans have met with some opposition from unions, which have regarded them as efforts to weaken employee organization. The plans have lost employee support when profits were reduced in periods of business recession. Too often they have been established as a substitute for a broad-gauge industrial relations program. It is clear that they are not a satisfactory substitute. They appear to have been successful only in situations in which the basic manpower management program has been carefully considered.*

4.2.5 Employee stockownership. Closely related to profit-sharing as a means of compensation are various provisions designed to encourage employee stockownership. In many situations these plans have developed from provisions in which employees were encouraged to accept profits in the form of stock.

Stockownership plans generally make stock available to employees at a special price and facilitate purchase on a time-payment basis. In some instances, a special issue of stock is authorized for this purpose. Stock thus sold to employees may be either voting or nonvoting. In some plans, only employees who have a stipulated length of service are eligible. Many plans restrict the resale of stock thus acquired, specifying that it must be offered first to the employer.

Like profit-sharing, employee stockownership is encouraged as a means of securing and holding employee interest in the business. Both arrangements are also designed to develop habits of thrift.

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* See Bryce M. Stewart and Walter J. Couper, *Profit Sharing for Wage Earners and Executives* (New York: Industrial Relations Counselors, 1951); "Compensation for Executives," *Studies in Business Policy No. 13* (New York: National Industrial Conference Board, 1946); also Charles C. James, "The Pros and Cons of Profit Sharing," *Advanced Management*, Vol. 13, No. 3, September 1948, 111-115; Kenneth M. Thompson, *Profit Sharing* (New York: Harper and Brothers, 1949); Gustave Simons, "Economic and Legal Aspects of Profit-Sharing Plans," *Industrial and Labor Relations Review*, Vol. 2, No. 1, October 1948, 76-89; Joseph L. Scanlon, "Profit Sharing Under Collective Bargaining—Three Case Studies," *ibid.*, 58-75; *Profit Sharing* (Akron, Ohio: Council of Profit-Sharing Industries, 1951); *Pension and Profit Sharing Service*, Prentice-Hall, Inc., 70 Fifth Avenue, New York.

It may be questioned, however, whether employees should invest in the concern that employs them, thus putting all their eggs in one basket. In a serious recession, they may lose their jobs, dividends, and investment. For most wage-earners, common stocks in any industry may not represent a desirable form of savings.

4.3 MAJOR CONSIDERATIONS IN WAGE POLICY

Among the most important factors to be considered in formulating wage and salary policy are the following:

1. Legislation. Policy must be consistent with federal, state, and local legislation. Most important among such measures are the federal Fair Labor Standards Act, which specifies minimum wages and premium payments for overtime; federal prevailing wage and public contract laws (Davis-Bacon Act and Walsh-Healey Act); state prevailing wage and minimum wage laws, and "equal pay" laws requiring identical rates for men and women.

2. Skill. Differentials based on skill are the oldest basis for variations in rates.

3. Tradition. Rate structures often reflect historic bases for differences. Although they may be outmoded, policy must move slowly in any attempt to vary from these practices.

4. Going rates. Established levels of payment must be carefully noted to avoid inter-plant inequities. In many cases, where master contracts are in operation, going rates will be the equivalent of union scales.

5. Intra-plant equities. Most managements are concerned with the equities of their own wage structures. In any balancing of factors, a high rating is given to a structure that assures internal fairness in rates.

6. Productivity. Although it cannot be said that compensation is paid only for output or production, certainly the contribution of the employee to the product or services is a major basis for wage or salary.

4.3.1 Major wage and salary problems. Lionel B. Michael has provided an excellent outline of the major problems of wage and salary administration. He lists five major categories, with numerous subdivisions, as follows:

"1. Basic policies
   a. Labor legislation
   b. Bargaining agreements
   c. Management policies
2. Wage and salary structure
   a. Establishment of jobs
   b. Determination of relative value of jobs
   c. Determination of prevailing area rates
   d. Establishment of wage and salary scales
3. Indirect-payment practices
   a. General types of practices
   b. Factors determining which are established
   c. Criteria for determining extent of practices
   d. Application of practices—inter-plant and intraplant
   e. Acquainting employees with practices
4. Direct-payment plans
   a. General types of plans
   b. Criteria for applicability of plans
   c. Requirements of a successful wage-incentive plan
   d. Policy decisions required
   e. Methods study and methods information
   f. Methods of time determination
   g. Types of allowances
   h. Advantages of a wage-incentive plan
5. Employee assignment, performance appraisal, and rate adjustment
   a. Assignment of employees to jobs
   b. Appraisal of employee performance
   c. Assignment and adjustment of employees' rates" *

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* By permission from *Wage and Salary Fundamentals and Procedures*, by Lionel B. Michael. Copyright 1946, 1947, 1950, McGraw-Hill Book Company, Inc., pp. 7-8.

4.4 COST-OF-LIVING AND PRODUCTIVITY ADJUSTMENTS

Escalator clauses in negotiated labor agreements and unilateral decisions of managements made cost-of-living adjustments in wages more common after World War II. At the same time, increasing numbers of firms have provided—either unilaterally or by agreement—for improvement factors or productivity increases.

4.4.1 Policy statement. In general, provisions for cost-of-living adjustments tie wage adjustments to a local index of consumers' prices. They provide that for each increase or decrease of a stipulated degree in the index a similarly stipulated adjustment shall be made in wage rates—or in base rates for employees who are paid on an incentive basis. A sample provision, as stated in a collective agreement, may make this provision clear:

> *Percent Wage Adjustment, Based on Percent Change in Index; Adjustments at 3-Month Intervals; Limits on Downward Adjustments*
>
> As used hereinafter, the "base level" of the cost of living in (city) shall be considered to be at 130.5 index points, as shown upon the Consumers' Price Indexes for Moderate Income Families, published by the Bureau of Labor Statistics of the United States Department of Labor.
>
> Upon every rise or fall in said "Consumers' Price Indexes for Moderate Income Families" for (city) of 3 per cent or more of its base level, the employer will increase or decrease the wages of each of his employees by an equal percentage of those wages on the date of said increase or decrease; Provided, however, that no such increase or decrease shall be made before August 15, ——, or less than 3 months after any prior such change in wages; and no such change in wages shall bring about a reduction of the wages of any employee below the level of those wages 1 week after the date of the execution of this agreement, or below the minimum wage rates hereinafter provided.*

* Additional examples are available in "Collective Bargaining Provisions; Wage Adjustment Plans," *Bulletin No. 908-9*, Bureau of Labor Statistics, 1948.

4.4.2 Local indexes. Since the determining factor in such adjustments is the local index of consumers' prices, the particular index to be used must be specified. Indexes are provided by the Bureau of Labor Statistics only for major cities and only on predetermined dates. Some indexes are available monthly, some quarterly. The BLS index is by far the most widely used for this purpose. The other major index is that maintained by the National Industrial Conference Board. NICB indexes are available for a somewhat larger list of cities than are BLS indexes.

The BLS provides periodic cost-of-living data for 34 cities on the dates shown below:

Every month	*Jan., April, July, Oct.*
Birmingham	Buffalo
Boston	Denver
Chicago	Indianapolis
Cincinnati	Kansas City
Detroit	Manchester
Houston	Portland, Ore.
Los Angeles	Richmond
New York	Savannah
Philadelphia	
Pittsburgh	

Feb., May, Aug., Nov.	*March, June, Sept., Dec.*
Atlanta	Baltimore
Cleveland	Jacksonville
Milwaukee	Memphis
New Orleans	Minneapolis
Norfolk	Mobile
Scranton	Portland, Me.
Seattle	St. Louis
Washington	San Francisco

The NICB provides cost-of-living data for 54 cities on the dates shown on p. 236.

BLS data are first released in mimeographed form and are subsequently published in the *Monthly Labor Review*. NICB data are summarized in the *Management Record* and the *Economic Almanac*.

If these nationally oriented indexes are not available, it is possible, of course, to prepare and maintain a local index. The procedure is, however, complicated and expensive. It is always possible, of

Every month	*Jan., April, July, Oct.*
Birmingham	Baltimore
Boston	Bridgeport
Chicago	Dayton
Denver	Erie, Pa.
Detroit	Grand Rapids
Indianapolis	Green Bay
Los Angeles	Houston
New Orleans	Memphis
New York	Minneapolis-St. Paul
Philadelphia	Newark
	Omaha
	Roanoke
	Sacramento
	Seattle
	Syracuse

Feb., May, Aug., Nov.	*March, June, Sept., Dec.*
Akron	Atlanta
Chattanooga	Buffalo
Cincinnati	Cleveland
Dallas	Des Moines
Duluth	Evansville
Fall River	Huntington
Muskegon	Kansas City, Mo.
New Haven	Lansing
Pittsburgh	Louisville
Richmond	Milwaukee
Rochester	Portland
St. Louis	Providence
San Francisco-Oakland	Spokane
Wilmington	Toledo
	Trenton

course, for local wages to be keyed to one of the metropolitan areas for which indexes are available, although it must be evident that local costs follow the pattern of the metropolitan area.

4.4.3 Tandem adjustments. Intraplant inequities may be created if only a portion of the work force enjoys escalator provisions while other employees do not. During the period of governmental wage stabilization following World War II, the Wage Stabilization Board developed the principle of tandem adjustments for employees who were thus adversely affected. The principle is sound whether or not public regulations limit wage adjustments. If a portion of the work force receives an increase because of higher living costs, equity requires that other employees whose wages, salaries, or earnings have long been closely related to those that are increased should be similarly treated.

4.4.4 Improvement factors. The basic idea of the improvement factor holds that employees should share in constantly increasing productivity through higher wages. Earlier practice has generally assumed that increasing productivity will result in economies and thus be reflected in falling prices—thus increasing the real value of employee earnings. The improvement factor assumes that a superior means of distributing gains in productivity compensates employees directly for these increases.

Wages are not adjusted for annual increases in a particular plant or firm. Rather, adjustments are based on nationwide calculations of increasing over-all productivity in manufacturing industries. Since annual increases in productivity amount to between 2 and 3 per cent, wage adjustments are made in a similar proportion. In plants in which no such increase has been made, these provisions may create serious problems. They may also stimulate a growing pressure for methods of increasing productivity, including technological changes.

4.5 INCENTIVE WAGES

The essence of so-called incentive wage plans is that they adjust earnings to output or production, thus providing a special financial incentive for increasing effort. The simplest form is the piece rate. Common usage, however, reserves the title of incentive wage plans for more complicated arrangements that introduce considerations of time-saving, overhead costs, and others into the calculation of earnings. In general, these plans may be differentiated according to their tendency to increase or decrease piece rates as production rises. They may also be distinguished in terms of their applicability to both standardized and unstandardized working assignments and conditions. In addition, some of the plans have the special

advantage of facilitating transfers from one job to another by defining all jobs in terms of uniform work units.

So far as detailed provisions are concerned, the variety of plans is almost endless. All, however, are marked by a

TABLE 4.7 BASIC INCENTIVE WAGE PLANS (Data simplified for purposes of illustration.)

THE TAYLOR DIFFERENTIAL PIECE-RATE PLAN

Data: Normal weekly wage, $40 (40 hours); standard output, 4 units per week, 10 hours per unit. Two piece rates: standard and above, $10 per piece; under standard, $7.50 per piece.

Employee	Units per week	Piece rate	Weekly earnings
A	3.6	$ 7.50	$27.00
B	4.0	10.00	40.00
C	6.0	10.00	60.00
D	8.0	10.00	80.00

THE HALSEY PLAN

Data: Normal weekly wage, $40 (40 hours); normal hourly rate, $1.00; normal output or production, 4 units per week, 10 hours per unit; earnings, time taken at hourly rate plus premium; guaranteed weekly wage, $40; premium, 50 per cent of time rate for time saved.

Employee	Units per week	Time taken per piece, hours	Time saved per piece, hours	Hours saved	Base wage	Premium for time saved	Weekly earnings
A	3.6	11.1	. . .	None	$40	. . .	$40
B	4.0	10.0	. . .	None	40	. . .	40
C	6.0	6.7	3.3	20	40	$10	50
D	8.0	5.0	5.0	40	40	20	60

THE ROWAN PLAN

Data: Normal weekly wage, $40 (40 hours); normal hourly wage, $1.00; normal output or production, 4 units per week, 10 hours per unit; earnings, time taken at hourly rate plus premium; guaranteed weekly wage, $40; premium hourly rate is base rate plus percentage of time saved.

Employee	Units per week	Time taken per piece, hours	Time saved per piece, hours	Per cent normal time taken per piece	Per cent normal time saved per piece	Hourly rate	Weekly earnings
A	3.6	11.1	. . .	111.1	. . .	$1.00	$40.00
B	4.0	10.0	. . .	100.0	. . .	1.00	40.00
C	6.0	6.7	3.3	66.7	33.3	1.33	53.20
D	8.0	5.0	5.0	50.0	50.0	1.50	60.00

TABLE 4.8 BASIC INCENTIVE WAGE PLANS (Data simplified for purposes of illustration.)

THE ONE HUNDRED PER CENT PREMIUM PLAN

Data: Normal weekly wage, $40 (40 hours); standard output or production, 4 units per week, 10 hours per unit; standard hourly rate, $1.00; earnings, time taken at standard hourly rate plus premium; guaranteed weekly wage, $40; premium, payment for time saved at full hourly rate.

Employee	Units per week	Time taken per piece, hours	Time saved per piece, hours	Total hours saved	Base rate pay	Premium	Weekly earnings
A	3.6	11.1	. . .	. . .	$40	. . .	$40
B	4.0	10.0	. . .	. . .	40	. . .	40
C	6.0	6.7	3.3	20.0	40	$20	60
D	8.0	5.0	5.0	40.0	40	40	80

THE GANTT TASK AND BONUS SYSTEM

Data: Guaranteed weekly wage, $40.00; standard output or production, 4 units per week, 10 hours per unit; standard time rate, $1.00 per hour; earnings, standard and above, time allowed at standard time rate plus premium; below standard, guaranteed weekly wage; premium, 20 per cent of payment for time allowed.

Employee	Units per week	Standard hours allowed	Wage for time allowed	Premium	Weekly earnings	Labor cost per piece
A	3.6	36	$40.00	. . . .	$40.00	$11.11
B	4.0	40	40.00	$ 8.00	48.00	12.00
C	6.0	60	60.00	12.00	72.00	12.00
D	8.0	80	80.00	16.00	96.00	12.00

few basic arrangements. The provision that will be desirable in any specific plant or department cannot be forecast without a careful analysis of the operations performed. Here, however, it may be well to outline the operation of the older and more basic plans. They can be adapted to specific situations upon the basis of careful study and understanding.

4.5.1 Basic plans. To provide a handy reference, five of these basic plans are illustrated in Tables 4.7 and 4.8. Each plan is shown operating with the same variations in output, in order to make the distinctive features of each plan readily apparent. The Taylor plan is selective, in that it provides a high piece rate for high-output employees and a low rate to discourage those who cannot make standard. Halsey and Rowan plans differ in the rate of earnings provided for employees who exceed standard. The results of these basic plans on earnings and labor costs are illustrated in Figs. 4.19 and 4.20.

4.5.2 General principles. Several general principles, based on extensive experience with incentive plans, may be stated as follows:

1. Because many employees are skeptical of incentive plans, and also because the plans must be adapted to the situation in which they are used, an incentive plan must be thoroughly worked out and explained to all those who will be affected by it.

2. Expected earnings must be higher than those provided by hourly rates. Increases ranging from 15 to 25 per cent are widely regarded as about right.

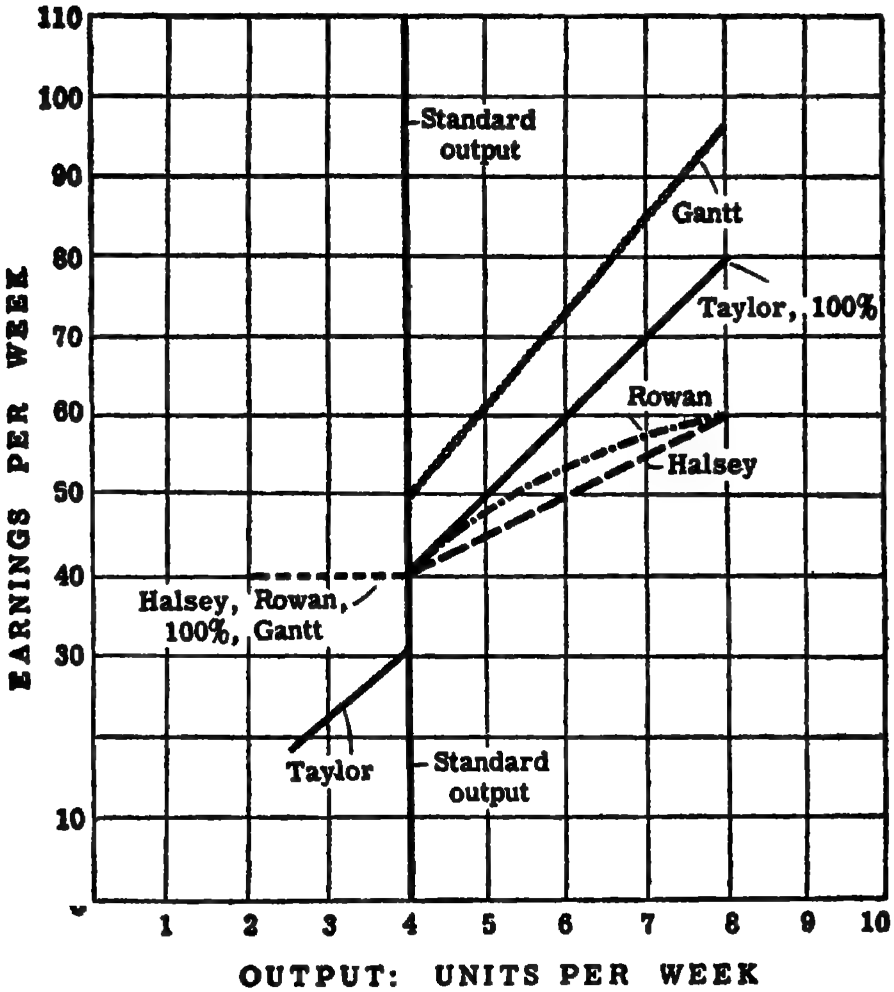


FIG. 4.19 WEEKLY EARNINGS UNDER BASIC INCENTIVE WAGE PLANS.

3. A small proportion of all employees—those who are especially apt in various operations—earn as much as 50 per cent more than this average.

4. Arrangements that provide for a declining rate for higher levels of output are not generally acceptable, except possibly at very high levels where a negative incentive may protect the health of the employee.

5. Establishing bases or standards of output is a matter of major concern in all incentive plans. Time studies—for each job—represent the most satisfactory means of setting fair standards. Base rates derived from experience under unstandardized conditions are seldom reliable. (See Section 5.)

6. Rates on various jobs must be properly interrelated. Job evaluation is probably the most satisfactory means of establishing such relationships.

7. Means must be provided for periodic review of rates to make sure that they are appropriately related to each other and are fair in terms of possible earnings on other jobs.

8. Means must be provided to insure prompt adjustments in rates for changes in job content.

9. Time studies may be conducted and rates established unilaterally by the employer or jointly with unions of employees. In either case, arrangements must be maintained for appealing such rates. Mistakes can be and are made, and their correction must be assured.

10. Although rates are reviewed periodically, no change should be made merely because employees are earning

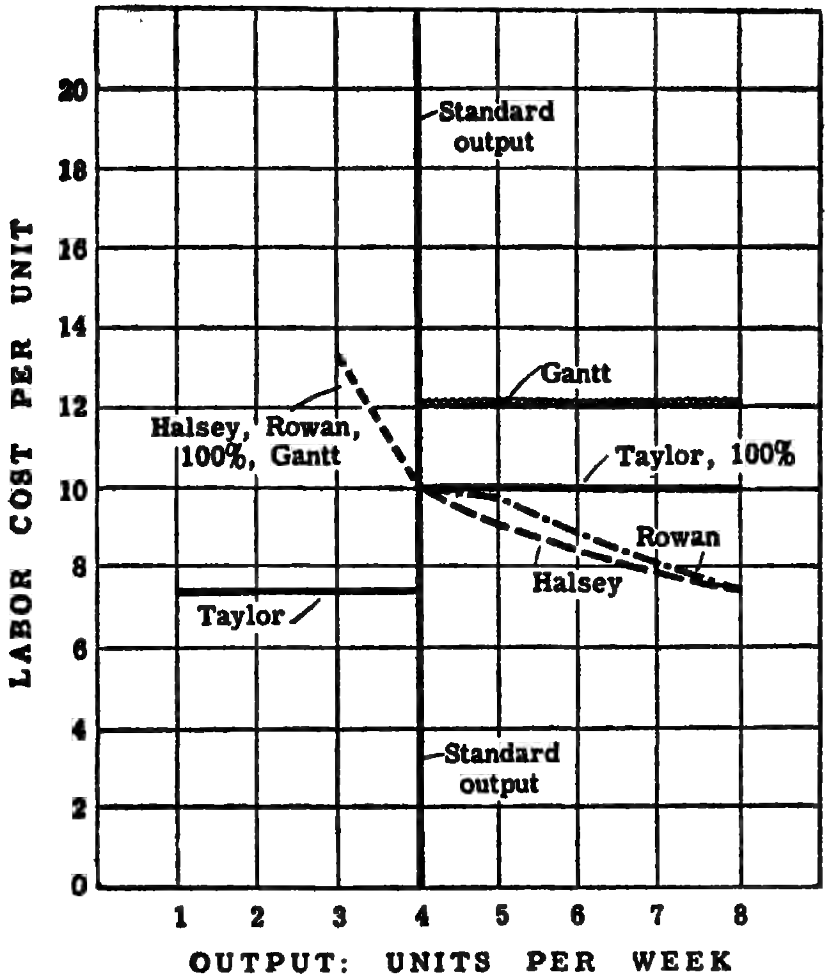


FIG. **4.20** UNIT LABOR COSTS UNDER BASIC INCENTIVE WAGE PLANS.

"too much." This does not mean that rates can never be reduced. Newly established rates may err on the liberal or "loose" side as well as on the "tight" side. If they reflect improper standards, the standards should be revised. Further, if jobs change, standards and rates must be reviewed.*

* For sources of additional information on incentive plans, see Robert L. Aronson, "Incentive Wage Systems: A Selected, Annotated Bibliography," Industrial Relations Section, Princeton University, May, 1949; John M. True, "Incentive Wage System, A Selected Bibliography," Industrial Relations Section, Princeton University, 1947; John W. Riegel, "Paving the Way for an Incentive Plan," Industrial Relations Section, California Institute of Technology, 1943; R. A. Olson, "The Standard Movement Time Approach to Incentives," *Factory Management and Maintenance*, Vol. 104, No. 2, March 1946, 126 ff.

4.5.3 Basic considerations. W. H. Spencer has provided a list of 11 basic considerations in planning incentive wages. He concludes that to be successful, a plan should:

"1. Fit the plant and its operation.

2. Have the understanding and interest of top management.

3. Have the constant attention of competent supervisors.

4. Have standards fixed and guaranteed against changes, except when there are changes in methods, material, or product.

5. Have standards directly measuring the productivity.

6. Be understandable to and accepted by the workers.

7. Be as simple as possible and still be a direct measure of the productive effort of the worker.

8. Not appreciably increase unit labor cost.

9. Not pay a premium for productivity below that which should exist.

10. Not be a subterfuge to increase pay without a corresponding increase in productivity.

11. Not be a scheme to avoid a justifiable base hourly increase." *

4.5.4 Union attitudes. It is often stated that unions are opposed to piece-rate or more complicated incentive wage plans. This generalization is unjustified, for some unions regularly insist upon such a method of payment. On the other hand, it is true that many unions have opposed these plans. Other unions have indicated the conditions they regard as essential in such arrangements. For example, a statement of the UAW-CIO outlined seven considerations, as follows:

"1. No system of incentive wage payment shall be applied before it has received the approval of the membership of the local union or the plant unit and of the International Union.

"2. The local union or plant unit operating under a wage incentive system shall retain the right at any time to eliminate such a system when it has become apparent to the union that such a system is failing to secure the objectives for which it was established.

"3. In the event that any U.A.W. plant now operating on a day-rate basis shall convert to an incentive system, guaranteed hourly base rates under such a system shall be no less than the previous hourly day rates in all classifications.

"4. Incentive payments above the base rate for all productive workers shall be in direct proportion to the increase of production above previously established normal standards. Incentives shall be computed on an hourly or daily basis.

"5. Base rates and production standards shall remain unchanged, except when in the opinion of the union and the company substantial changes in product, methods, or equipment shall have taken place.

"6. Some method of participation in incentive earnings must be insured for non-production workers as well as direct production workers. Such participation, however, must not be at the expense of earnings to be received by production workers.

"7. The introduction of incentive systems must be restricted to plants now able to assure either full and continuous weekly employment or a guaranteed weekly wage equal to 40 times the basic hourly rate." *

4.5.5 General effects on earnings. Incentive earnings are generally higher—for the same job—than straight time wages. When incentive plans are installed, they should be expected to provide hourly earnings at least 20 per cent higher, on the average, than earlier hourly rates. Comparisons of occupational rates in large numbers of plants indicate a similar differential in established time rates and incentive earnings.

4.5.6 Incentives and non-production employees. Use of incentive plans often creates problems in compensating supervisors and other employees not included in the plans. Some of these problems are solved by so-called "group incentives," in which supervisors are included as members of a working group and each member's bonus or premium is dependent on the output of the group. In other situations, adjustments are made in the pay of supervisors and of all non-production employees whose effort is affected by varying output.

4.6 JOB EVALUATION

Job evaluation involves the systematic appraisal of each job in the organization to determine its com-

* W. H. Spencer, "Wage Incentives from a War Production Viewpoint," *Proceedings, Third Annual Conference on Industrial Relations,* April 19, 20, 21, 1945 (University of Minnesota, Center for Continuation Study and Industrial Relations Center, 1945), 7-8. Reprinted by permission.

* *Executive's Labor Letter* (New York: National Foremen's Institute), April 20, 1943, p. 4. Reprinted by permission.

parative value. All the procedures used in job evaluation seek to discover what each job involves in terms of the considerations for which wages are paid. Job evaluation seeks to provide for a fair and equitable wage structure based on the assumption that each job should be paid according to its contribution to the value of the finished product or service and to the long-term success and progress of the organization.

Job evaluation helps prevent and remove intra-plant inequities. However, since it lays a useful foundation for job comparisons from one plant and firm to another, it is also helpful in reducing inter-plant inequities. In practice, the determination of wage rates often makes use of wage and salary surveys, which immediately introduce inter-plant considerations.

4.6.1 Systems. Four principal systems of job evaluation may be distinguished. All involve the rating of jobs, but they differ in methods and procedures. They are: job ranking, job classification, point-value or "manual" systems, and the factor-comparison system.

4.6.1.1 Job ranking. This is the simplest system. As usually applied, it assigns no point values to individual jobs. Rather, it establishes a *job structure* or *hierarchy* without attempting to measure the differences in value from one level to another. In practice, job ranking usually begins by noting several job elements or factors to be considered in comparing jobs. Then the jobs are ranked from those having the fewest requirements to those having the most.

The whole procedure is comparatively informal. The rankers are presumed to be familiar with the entire organization, which means that this system is generally used in small firms and agencies. They study job descriptions or notes on each job and arrange slips or cards to indicate the resulting job structure. Subsequent discussion seeks to adjust compensation to differences in the levels thus established.

4.6.1.2 Job classification system. Another procedure that is best adapted to small organizations—although it has been used in some very large ones—is known as job classification. It begins by noting major classes of jobs—for example, clerical, engineering, sales, and accounting. Variations in skill requirements, administrative responsibility, and other factors are then considered. On the basis of these differences, job *series* and *classes* are created, such as an engineering series or a sales series. Several classes may be defined within each series. Existing jobs are then "slotted" into this classification.

4.6.1.3 Point or manual system. The point or manual system is essentially the application of a job *rating scale* to each job. This scale outlines a series of job elements of qualities. For each element a *descriptive scale* is provided which defines various degrees of the element. Each degree includes a range of points, from which the appropriate point value is selected. The combined scale totals these points to provide an over-all point value for each job.

The key to satisfactory job evaluation under this system is to develop a satisfactory rating scale and to teach staff members to use it. A variety of scales is available. Some are of limited applicability, having been developed to fit the needs of one organization. Others, like the National Metal Trades Association scales, are designed for use throughout a large industry. Committees have been widely used to develop special tailor-made scales. Such committees may include representatives of several levels of supervision as well as rank-and-file employees and union representatives.

4.6.1.4 Factor-comparison method. The factor-comparison method provides a tailor-made system for each application. It begins by asking what job elements or factors the particular agency or firm pays for. Job descriptions disclose the major job elements that appear —in greater or less degree—in all jobs throughout the organization. Next, the comparative money value of each factor is sought. A list of "key" or widely known jobs, with their rates of pay, is submitted to a committee. Each member is asked to indicate the proportion

"B" JOB VALUATION

JOB REQUIREMENTS	DEGREE 1	2	3	4	5	TOTAL POINTS
SKILL						
1. Experience	2-6-10-14-18-22	24-28-32-36-40-44	46-50-54-58-62-66	68-72-76-80-84-88	90-94-98-102-106-110	
2. Education	2-4-6-8-10-12-14	16-18-20-22-24-26-28	30-32-34-36-38-40-42	44-46-48-50-52-54-56	58-60-62-64-66-68-70	
3. Initiative and Ingenuity	2-4-6-8-10-12-14	16-18-20-22-24-26-28	30-32-34-36-38-40-42	44-46-48-50-52-54-56	58-60-62-64-66-68-70	
EFFORT						
4. Mental or Visual Demand	2-4-6-8	10-12-14-16	18-20-22-24	26-28-30-32	34-36-38-40	
5. Physical Demand	1-3-5-7	8-10-12-14	15-17-19-21	22-24-26-28	29-31-33-35	
RESPONSIBILITY						
6. Spoilage of Materials	1-2-3-4-5	6-7-8-9-10	11-12-13-14-15	16-17-18-19-20	21-22-23-24-25	
7. Damage to Machines or Equipment	1-2-3-4-5	6-7-8-9-10	11-12-13-14-15	16-17-18-19-20	21-22-23-24-25	
8. Work of Others	1-2-3-4-5	6-7-8-9-10	11-12-13-14-15	16-17-18-19-20	21-22-23-24-25	
9. Safety of Others	1-2-3-4-5	6-7-8-9-10	11-12-13-14-15	16-17-18-19-20	21-22-23-24-25	
WORKING CONDITIONS						
10. Hazards to Self	2-4-6-8	10-12-14-16	18-20-22-24	26-28-30-32	34-36-38-40	
11. Surroundings — Environment	1-3-5-7	8-10-12-14	15-17-19-21	22-24-26-28	29-31-33-35	

(a) Present Hourly Rate______¢ (b) Average Hourly Earnings______¢ (c) New Valuation Per Hour______¢ Total Points

(d) Job Name______ (e) Plant Job No.______ (f) U. S. E. S. Code______ (g) Labor Grade______

Reproduced by permission from Ray E. Hibbs, *Job Evaluation by the Precision Method* (Minneapolis: Ray E. Hibbs and Associates, 1944).

FIG. **4.21** JOB EVALUATION SHEET FOR INDIVIDUAL JOB.

of total pay for each job he thinks is attributable to each factor. Analysis of these allocations provides comparative weights for each job factor.

Key jobs are then analyzed to provide yardsticks for each job factor. Each job in the organization is rated on each factor by reference to scales constructed by an analysis of these key jobs. In the factor-comparison procedure, the distinctive features are (1) the discovery and comparison of job elements or factors in key jobs, and (2) the comparison and appraisal of all other jobs on the basis of these job elements.*

Figures 4.21 and 4.22 illustrate the rating procedure employed in the application of a point system.

4.6.2 Wage and salary structures. Job evaluation assigns a relative position, generally indicated by point values, to each job. Wage payments are thereafter presumably related to this position. But it is not usual to provide a distinctive wage rate for each job in the organization. Rather, jobs having similar ratings or values are grouped in labor grades, thus providing a hierarchy of positions and rates and creating a wage or salary structure. Figure 4.23 is a graphic illustration of such a structure.

4.6.3 Wage surveys. Decisions on what rates are to be paid on each job or each class or labor grade may be either uni-

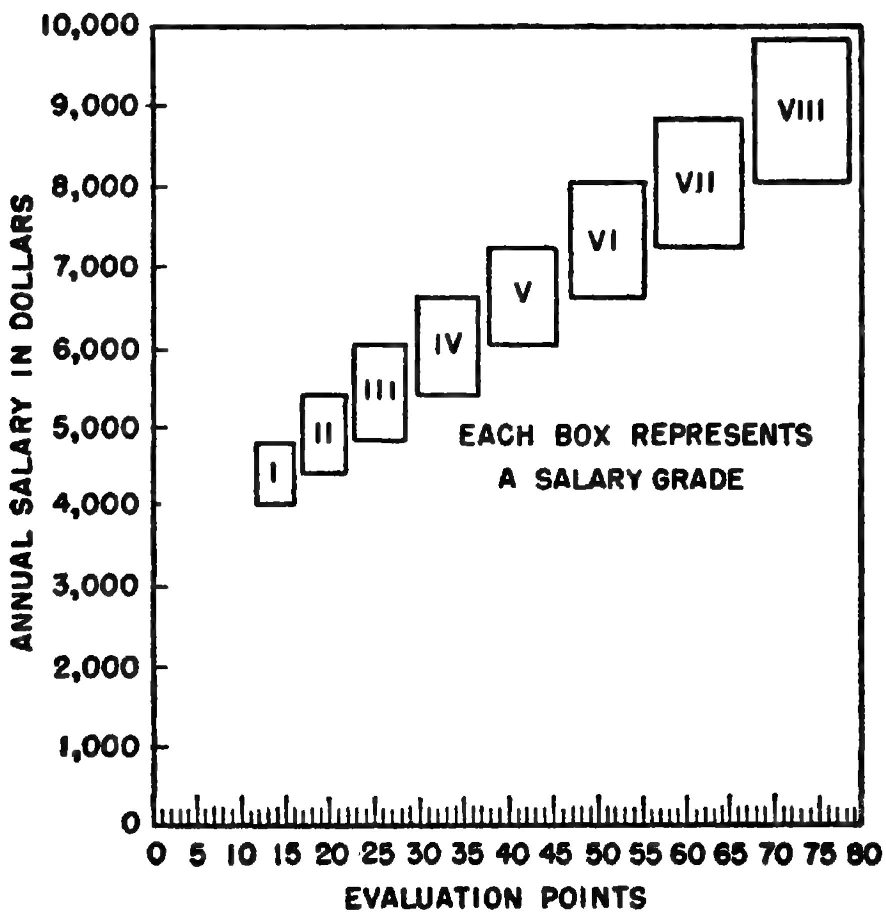
* For greater detail on these and other plans, see Jay L. Otis and Richard Leukart, *Job Evaluation* (New York: Prentice-Hall, Inc., 1948); William R. Spriegel, "Job Evaluation in Insurance Companies," University of Texas Bureau of Business Research, 1951; C. A. Lawshe and P. C. Farbo, "Studies in Job Evaluation," *Journal of Applied Psychology*, Vol. 33, No. 2, April 1949, 158-166; Eugene J. Benge, "Statistical Study of a Job Evaluation Point System," *Modern Management*, Vol. 7, No. 3, April 1947. 17-22); D. J. Chesler, "Reliability and Comparability of Different Job Evaluation Systems," *Journal of Applied Psychology*, Vol. 32, No. 5, October 1948, 465-475); also his "Reliability of Abbreviated Job Evaluation Scales," *Journal of Applied Psychology*, Vol. 32, No. 6, December 1948, 622-628; and his "Abbreviated Job Evaluation Scales . . . ," *Journal of Applied Psychology*, Vol. 33, No. 2, April 1949, 151-157; P. Ash, "The Reliability of Job Evaluation Rankings," *Journal of Applied Psychology*, Vol. 32, No. 3, June 1948, 313-320; Leonard Cohen, "More Reliable Job Evaluation," *Personnel Psychology*, Vol. 1, No. 4, Winter 1948, 457-464; Clark Kerr and Lloyd H. Fisher, "Effect of Environment and Administration on Job Evaluation," University of California (Berkeley) Institute of Industrial Relations, *Reprint No. 21*, 1950.

FIG. **4.22** CHECKING SCALE FOR SINGLE FACTOR*

	1st DEGREE	2nd DEGREE	3rd DEGREE	4th DEGREE	5th DEGREE
2. EDUCATION OR TRADE INFORMATION This factor appraises the necessary requirements for the use of graphs, drawings, shop mathematics, measuring instruments and trade information. The ability to speak and understand English is assumed to be present in all cases.	May require ability to read, write, add and subtract.	Requires use of simple mathematics, such as, addition and subtraction of fractions and decimals; the use of drawings and such measuring instruments as scales or caliper. Education equivalent of sixth grade.	Requires shop math, chemical, physical or engineering formulas, a number of precision measuring devices or fairly involved drawings. Some trade information in a special field is required.	Advanced shop math, or a wide range of precision measuring devices, wide trade information, involved drawings, graphs and specifications are required. Equivalent to one year college or 4 years trade training.	Technical knowledge great enough to handle advanced mechanical, electrical or other technical problems. Approximately equivalent to four years of technical training at the college level.
	EXAMPLE OF JOBS	EXAMPLE OF JOBS	EXAMPLE OF JOBS	EXAMPLE OF JOBS	EXAMPLE OF JOBS
	Drill Press Laborer Polisher and Buffer Hand Trucker	Assembler Drill Press Polisher and Buffer Punch Press Operator Weighing articles on ordinary scales.	Automatic Screw Machine Operator Grinder, External Lathe Operator, Turret Millwright	Electrician Machinist (Production and Service) Tool and Die Maker	Inspector Tester

* Reproduced by permission from Ray E. Hibbs, *Job Evaluation by the Precision Method* (Minneapolis: Ray E. Hibbs and Associates, 1941).

FIG. **4.23** WAGE OR SALARY STRUCTURE.



From *Salary Freezing and How It works* (New York: Prentice-Hall, 1951), p. 16. Reproduced by permission.

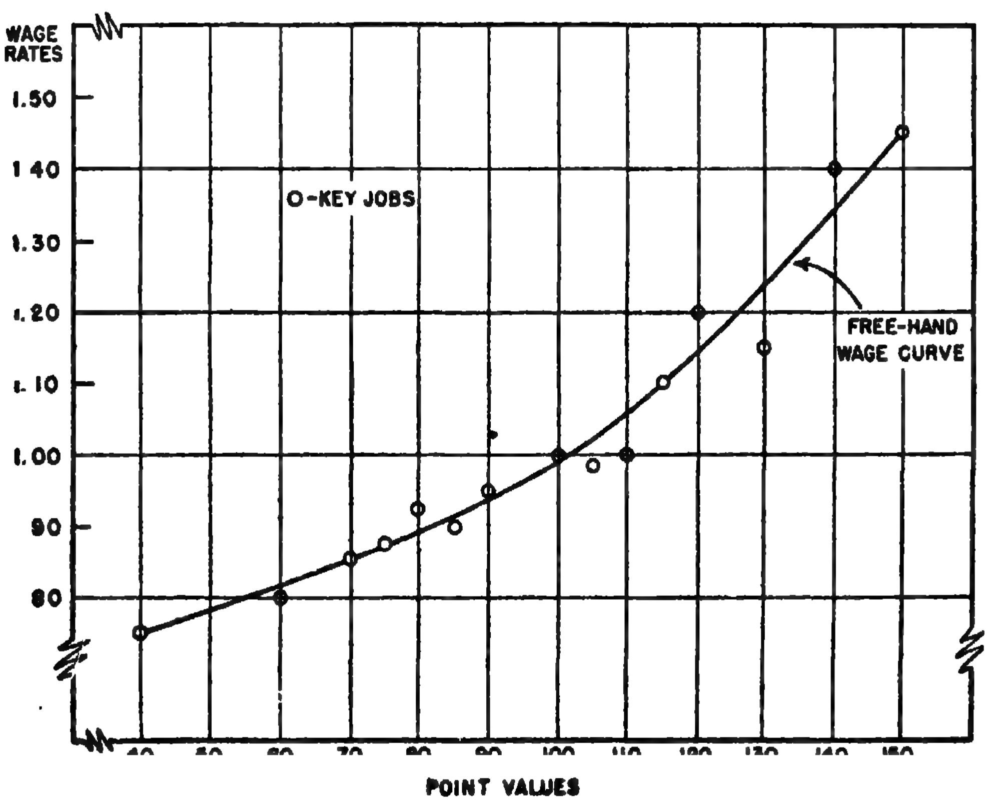
lateral or bargained. One of the common criteria is the going wage—the rates being paid for comparable jobs in other firms and localities. Frequently, information is sought on going wages in key jobs—those that are sharply defined and for which considerable numbers are employed—and then a straight line or parabolic curve is fitted to the points represented by these rates and the point values to which they correspond.

Wage surveys for this purpose are conducted regularly by employers' associations, unions, and governmental agencies. Procedure includes definition of the purpose of the survey, designation of the jobs to be covered, adoption of "standard" job descriptions, designation of firms or agencies to be surveyed, specification of the range of data to be secured (wage rates, hours, earnings, fringe items, etc.), preparation of schedules designed to secure such information, collection of data, and analysis and summary of results.*

Wage surveys are difficult to conduct. Job titles cannot be depended on; job

* See Stanley P. Farwell, "Uses of Wage Survey Data," in *Job Evaluation Practices,* University of Minnesota Industrial Relations Center, *Release No. 2,* February 1949; Richard C. Wilcock, "Types and Sources of Wage Data in Illinois," University of Illinois Institute of Labor and Industrial Relations, *Research Report No. 4,* September 1949. See also the "Wage Policies and Practices Survey of the Milwaukee Area," prepared by the Industrial Relations Division of Allis-Chalmers Manufacturing Co., or the "Wage Survey," regularly released to members by Associated Industries of Minneapolis and by Associated Industries of Missouri (St. Louis, June 1951); also *Wage Survey Report of Official Clerical Jobs* (Chicago: American Medical Association, 1950).

FIG. **4.24** CURVILINEAR WAGE CURVE FITTED TO POINT VALUES AND WAGE RATES FOR KEY JOBS.



content may show wide variation; methods of compensation vary; and compensation may be complicated by guarantees of employment or profit-sharing.

Data may be collected by interview or by mailed questionnaire. Generally the interview technique is preferred, since it allows more careful comparison of jobs. In the best practice, well-trained job analysts gather information on rates and study the jobs to note possible variations from a standard pattern.

Findings may be presented in terms of average rates on each job and distributions of rates about this average. The number of firms paying each rate may be noted, as may modal, median, and quartile rates for each job. Fringe items are also noted.

Figure 4.24 illustrates the procedure for fitting a wage curve to job-evaluation and wage-survey data.

4.6.4 Problems in application. Many problems arise in instituting and administering a job-evaluation program. No matter how carefully a plan is developed originally, it cannot be expected to operate without constant attention. Changes in job content and in the operation of labor markets may necessitate frequent adjustments.

4.6.4.1 Union attitudes. Unions have frequently advocated job evaluation as a means of increasing earnings, removing intra-plant inequities, and justifying wage structures to union members. On the other hand, unions have found some systems unsatisfactory and have opposed the going rate as a fair basis for setting wage curves. Union demands for across-the-board increases may quickly destroy the differentials in the job structure that have been defined by job evaluation. The extent to which unions should be asked to share responsibility in job evaluation is a matter on which opinions differ.

4.6.4.2 Managerial jobs. The usefulness of any job evaluation system depends on how applicable the job elements are. Consequently, a single system may not be appropriate throughout a complicated organization. White-collar positions, for example, may require a separate program, as may supervisory and managerial positions.*

5. EMPLOYEE MOTIVATION AND MORALE

In a sense, motivating employees is the fundamental problem of manpower management in a free society. For in such a society, employees must be encouraged to want to work effectively. In our present stage of economic and industrial evolution, those charged with managerial responsibilities must encourage self-motivation by providing reasons and incentives designed to stimulate enthusiastic participation in the modern industrial enterprise.

Such enthusiasm is widely described as "morale"—the attitudes with which individual employees and groups regard their work and their participation in the enterprise. Morale is said to be high when these attitudes are favorable and low when they are unfavorable.

5.1 PROBLEMS AND SYMPTOMS

Most approaches to the problem of maintaining a high level of motivation to date tend to eliminate or reduce dissatisfaction and irritations in employment. A more positive approach provides various employee services and benefits designed to make employment more attractive and to stimulate teamwork.

Among the common evidences of poor or inadequate motivation, the most important are:

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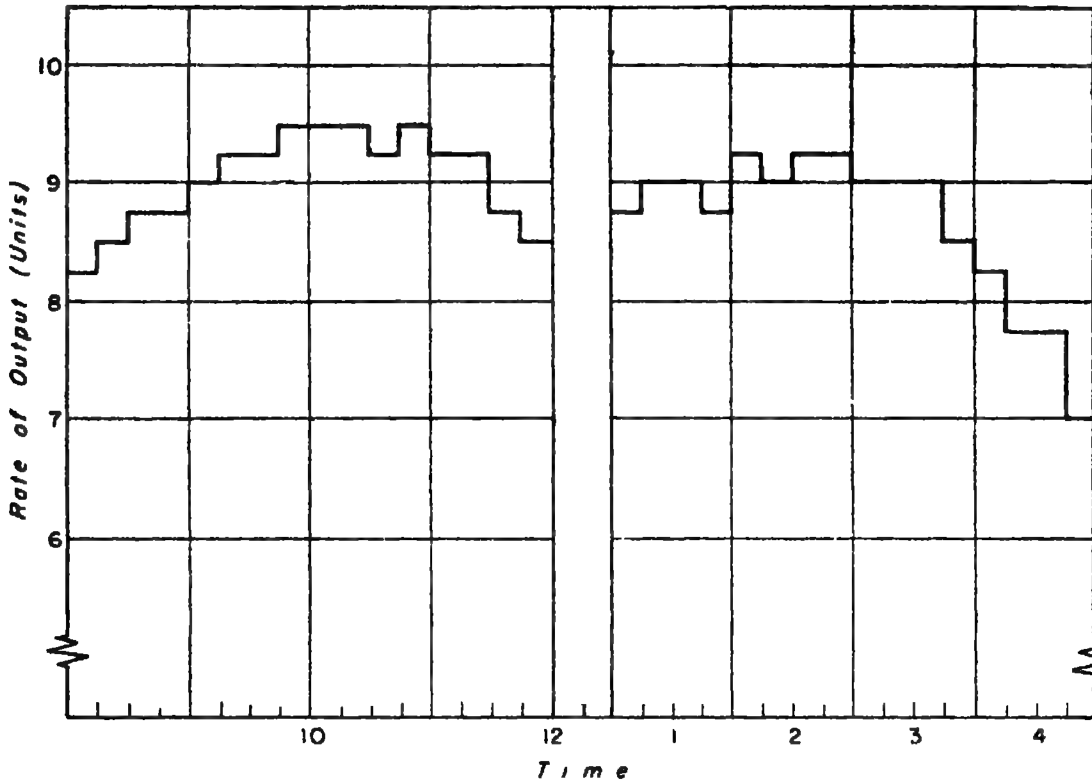
* See *Evaluation of Managerial Positions* (Chicago: Business Research Corporation, 1949); Albert N. Gillett, *How To Evaluate Supervisory Jobs* (Deep River, Conn.: National Foremen's Institute, 1947); Herbert S. Briggs, "Job Evaluation: Guide to Salaries," *Management Record*, Vol. II, No. 4, April 1949. 142-143; Ralph W. Ellis, "Integration of Hourly and Salaried Jobs," *Job Evaluation Practices*, University of Minnesota Industrial Relations Center, August 1950.



Yoder, *Personnel Principles and Policies*, pp. 348.

FIG. **4.25** FATIGUE CURVE OF OUTPUT.

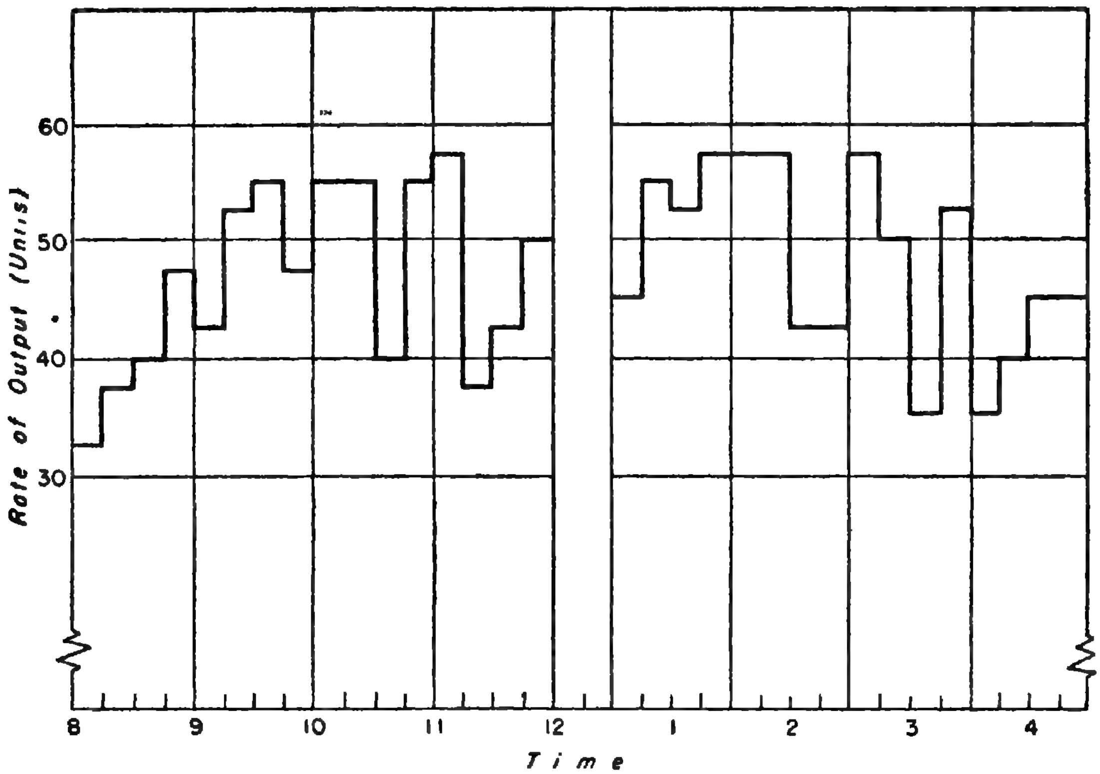
5.1.1 Fatigue and monotony. Interest and output decline as fatigue increases. Of course, fatigue may be due to excessive physical or mental demands on employees, or to the nature of working assignments. Whatever the cause, excessive fatigue is regarded as evidence of a motivation problem.

A useful method for discovering this condition is illustrated in Fig. 4.25. Output of individual employees is studied to discover fluctuations during fifteen-minute or half-hour periods throughout the working day. After a "warm-up" period at the beginning of morning and afternoon work periods, peak output is maintained for only a short time. Thereafter, output falls. This decline suggests the influence of fatigue.

Monotony is another condition that is reflected in output. Monotonous operations (or, rather, operations that appear to the individual employee as monotonous) tend to result in shifts of interest, with intervals of disinterest and daydreaming. These effects may be apparent in the overt behavior of the employee. They may be discovered by studying short work periods throughout the working day or shift. Such an analysis is illustrated in Fig. 4.26. The distinctive evidence of monotony is the "end spurt"—the tendency to increase output toward the end of each work period in apparent anticipation of release from the job.*

5.1.2 Work stoppages. In popular thinking, strikes and lockouts are regarded as the principal evidences of dissatisfaction and deficient morale. They are, however, only the most obvious and perhaps the final stage of the process in which industrial unrest develops. Several preceding stages are evident to those

* For actual data and charts of output, see Einar Hardin, "Measurement of Physical Output at the Job Level," *Research and Technical Report No. 10*, University of Minnesota Industrial Relations Center, August 1951. See also "Fatigue and Productivity," *Industrial Relations Digests*, Industrial Relations Section, Princeton University, September 1942. For an excellent discussion, see William Gomberg, "Measuring the Fatigue Factor," *Industrial and Labor Relations Review*, Vol. 1, No. 1, October 1947, 80-93.



Yoder, *Personnel Principles and Policies*, p. 349.

FIG. **4.26** MONOTONY CURVE OF OUTPUT.

who study the situation critically. To some extent, however, strikes do take the form of "waves" and appear to develop through some sort of social contagion. Hence alert manpower management seeks to anticipate them by watching for incipient stages and by maintaining a careful check on current industrial unrest in the same or in other industries. They recognize the strong seasonal pattern in strikes (strikes normally reach peak levels in April, May, and June, fall off during summer months, pick up in the fall, and decline to lowest levels during December, January, and February). Current reports on work stoppages are published in the *Monthly Labor Review*.

5.1.3 Labor turnover. Perhaps the most widely recognized index of unrest, dissatisfaction, and poor morale, so far as professional employee relations staff members are concerned, is labor turnover. The term refers to the separation and replacement of members of the working force. In general, increasing labor turnover is regarded as a crude indicator of employee dissatisfaction, although many other conditions also exert a strong influence. Expansion and contraction of business activity, for example, inevitably affect hiring and separation. For this reason, replacements receive closer attention than other crude measures of turnover.

Three types of crude turnover rates are calculated: accession, separation, and replacement rates. For published rates, compiled by the Bureau of Labor Statistics, the base is the same—the average number of employees on the payroll during the period, which is usually a month. The average is obtained by adding the total number of employees on the payroll at the beginning of the period to the total number at the end, and dividing by two. Each rate is calculated as the number of accessions, separations, or replacements per hundred members of the working force.

Such crude rates take no account of seasonal or cyclical expansion and contraction, nor do they reflect the period of exposure in terms of the number of working days.

In compiling annual rates, if they are

calculated directly from the data, the same method is used. For purposes of comparison, equivalent annual rates are sometimes computed by multiplying monthly rates by a factor representing the month's proportion of the year (in terms of actual rather than working days).

5.1.3.1 Refined rates. Refined rates of turnover are frequently provided by the employment relations staff of individual firms. These are unavoidable separation or quit rates. Unavoidable separations are those that are not occasioned by plant expansion or contraction, or by employment policies that require the release of married women, or by death or other circumstances beyond the control of the enterprise. Since these refined rates tend to reflect situations that cause employees to leave their employment of their own volition, they give a more reliable indication of the attractiveness or unattractiveness of employment.

5.1.4 Absenteeism, tardiness, and disciplinary cases. Dissatisfaction with employment is indicated by increased frequency of absenteeism, tardiness, and cases requiring disciplinary action.

5.1.5 Restriction of output. Carefully maintained records of output—corrected for conditions beyond the control of employees—may disclose evidence of intentional restriction. Figure 4.27 suggests an appropriate analysis. The hourly output of each work group is regularly compared, and employees are classified according to their individual contributions. Staff members are on the alert for negative skewness in the distribution and for any narrowing of the range of individual contributions, indicating a tendency toward bogeys, par or quota. A tendency toward the elimination of high producers is especially suspicious.*

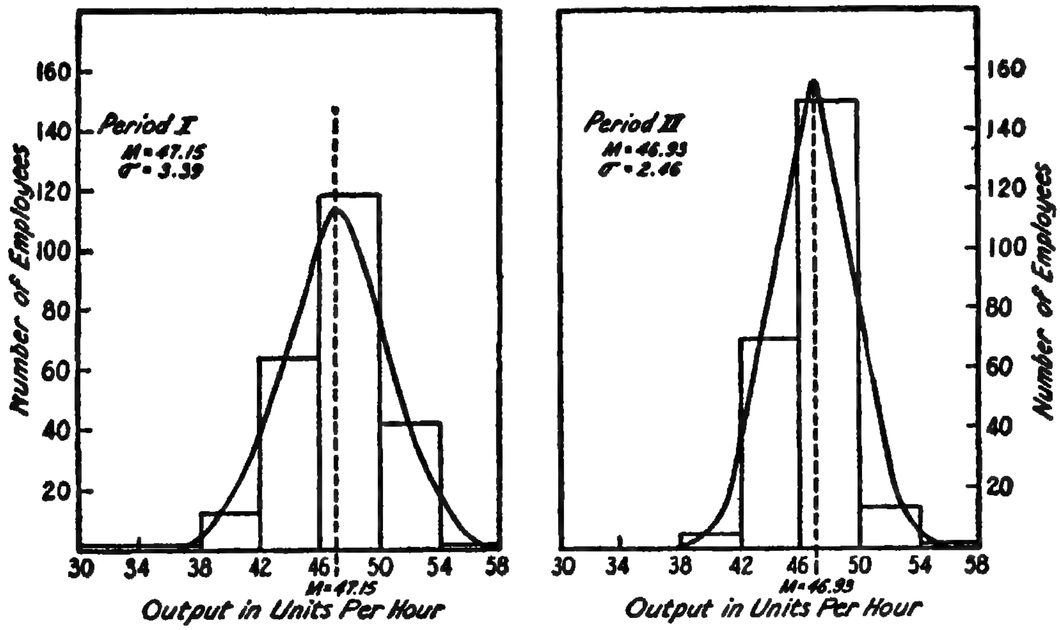
5.2 APPRAISAL OF EMPLOYEE MORALE

Isolated evidences of the decline or lack of morale are obviously useful. Many employers, however, prefer a continuing, regular measure of employee morale. In this positive and exploratory approach, attempts are made to note changes in employee attitudes and to provide a basis for action that will improve morale and maintain it on a high level.

5.2.1 Morale interviews. Currently, many managements conduct—usually through the employment relations staff—regular interviews with employees to keep themselves advised on prevailing levels of morale and on sources of irritation and dissatisfaction. Exit interviews, for example, may disclose situations in which the concern compares unfavorably with competing employment and may indicate serious sources of irritation among employees.

Major dependence, however, is placed on frequent and regular interviews with employees and supervisors. In these visits the interviewer encourages the employee to speak frankly about his job, his supervisors, his fellow employees, and any or all conditions affecting his employment. He is assured that what he says will not be recorded and that confidences will not be violated. The interviewer does not subsequently quote the interviewee on any of his suggestions for change. Morale interviews are essentially

* For greater detail, see Yoder, *Personnel Management and Industrial Relations*, pp. 472-474. For additional information, see "Controlling Absenteeism," U. S. Department of Labor, *Special Bulletin No. 12*, 1943; "Absenteeism," *Ohio Studies in Personnel No. 58*, Ohio State University Bureau of Business Research, 1950; Edgar L. Warren, "Thirty-six Years of National Emergency Strikes," *Industrial and Labor Relations Review*, Vol. 5, No. 1, October 1951, 3-19; Robert D. Loken, "Why They Quit," University of Illinois College of Commerce and Business Administration, 1951; Bernard J. Covner and Max Smith, "Times Absent vs. Days Absent as a Measure of Absenteeism," *Personnel*, Vol. 28, No. 1, July 1951, 23-27; Thomas C. Kent, "A Plan for Reducing Absenteeism," *Personnel Journal*, Vol. 30, No. 3, July-August 1951, 91-93; Willard A. Kerr, George J. Koppelmeier, and James T. Sullivan, "Absenteeism, Turnover, and Morale in a Metals Fabrication Factory," *Occupational Psychology*, Vol. 25, No. 1, January 1951, 50-55.



Yoder, *Personnel Management and Industrial Relations*, p. 472.

FIG. **4.27** ANALYSIS OF HOURLY OUTPUT TO DISCOVER CHANGES IN DISTRIBUTION.

unguided, although the interviewer may seek from time to time to focus attention on particular changes, arrangements, and problems. But for the most part, the interviewee is encouraged to talk about whatever interests him.

Since morale interviews are time-consuming, individual employees take part in them only infrequently. Because time is lost from work, these interviews may create administrative problems. They are highly personalized, since they are influenced by the individual characteristics of both the interviewer and the interviewee. Further, the comments of the employee may lose much of their significance when reported out of context. Similarly, the point of view of the interviewer may affect his interpretation of the employee's remarks. The results of morale interviws cannot be readily quantified and compared with results obtained at another time or in another setting. One interviewer's reports are not readily combined with another's. Only the most striking observations stand out in any generalizations based on the interviews; minor comments are lost.

5.2.2 Attitude surveys. Attitude surveys are made by means of oral or written questionnaires that cover a wide range of working conditions. Analysis of employees' replies provides a guide to general levels of morale as well as more specific indications of likes and dislikes.

Specific surveys may pinpoint certain conditions and situations. The attitude scale developed and used by the University of Minnesota Industrial Relations Center in its *Triple Audit,* for example, provides a general measure of morale for rank-and-file employees, plus measures or subscales in eight specific areas. Attitudes toward the employment situation as a whole are appraised, and a more sharply focused analysis discloses attitudes toward the firm or agency as an employer, in-plant communications, hours and pay, other working conditions, fellow employees, supervisors, types of work, and the union or unions of which employees are members.

5.2.2.1 Coverage—subject matter. Possible areas that may be covered in surveys are numerous. Benge has suggested some 40 specific items associated with attitudes toward the job, the supervisor, the management, and the com-

pany.* Valuable suggestions on areas to be covered may be secured from supervisors, from exit and counseling interviews, from the suggestion system, and from other attitude surveys.

The decision on what the survey should cover depends principally on what is to be done with the results. Are they to be casually noted, or will they be analyzed in great detail? Will disclosures from the survey be carefully considered as a basis for changing wages, hours, or other working conditions, for selecting or training supervisors, for improving employee handbooks, plant magazines, or other means of in-plant communication? Will the union or unions involved be given an analysis of employee attitudes toward union programs and activities?

5.2.2.2 Administration and analysis. Many managements conduct regular polls of employee attitudes, usually at six-month or annual intervals. Others employ outside consulting firms to conduct periodic surveys. Still others arrange for colleges and universities to manage surveys and to analyze results.

The question of sponsorship and administration has special importance, since employees may not express themselves frankly if their replies are to be analyzed by the firm's industrial relations staff. Even if questionnaires are unsigned, employees may fear that blanks have been coded or otherwise identified and that criticism may result in retaliation. For this reason, outside sponsorship by an agency in which employees have full confidence is regarded as highly important.

5.2.2.3 Method of distribution. Attitude questionnaires may be mailed to employees in their homes, or distributed with pay checks, or the employees may be called together and asked to fill out the questionnaires on company time. The method of distribution depends in part on the location of the plant or plants and on the number of employees to be included in the survey. Group meetings have several advantages. When employees are surrounded by others who are filling out questionnaires, they are encouraged to participate freely. Since the setting reminds many employees of a schoolroom, and the questionnaire suggests a test, they strive to do well on it. Also, in group meetings, representatives of the sponsoring agency can answer questions. If certain items or instructions are not clear, participants can ask for and obtain help. Finally, in group administration, employees can be given repeated assurances that their questionnaires will be kept confidential and will be seen only by an outside agency.

In contrast, when questionnaires are sent to the homes of employees, no informal advice can be given. Further, there may be some question about whose attitudes are recorded, since the items may be discussed extensively in the home. If questionnaires are not returned promptly, only a general reminder can be sent out, since the lack of signatures makes it impossible to identify those who have not replied.

5.2.2.4 Identification of returns. Although anonymity makes for frank answers, it also makes analysis of results more difficult. Consequently, some identification of the questionnaires is essential, particularly in medium-sized and large organizations. Interdepartmental comparisons can be made only if the departments are identified. Differences in the problems disclosed from one department to another—for example, different reactions to supervisors—may be among the most valuable findings of the survey. Many other types of highly significant analysis may depend on adequate identification. For example, attitudes may be compared on the basis of length of service, sex, education, marital status, number of dependents, union membership, level of wages, and other personal factors. Such analysis depends on at least limited identification.

5.2.2.5 Attitude scales. The questionnaires used in morale surveys may be either tailor-made for the individual

* Eugene J. Benge, *How To Make a Morale Survey* (Deep River, Conn.: National Foremen's Institute, 1941).

firm, or they may be designed for use in various situations. Most of the scales used by individual firms appear to have been built up of questions selected from other scales. Lack of standardization limits the value of such scales. Without average scores or norms, results must be interpreted on an *ad hoc* basis. Useful comparisons are limited to periodic and interdepartmental similarities and differences. This situation is improving as a few scales are being applied to many firms in a wide range of industries, so that generalizations as to what may be regarded as average, high, and low scores can be made.

The questions used in attitude scales should be framed in simple language and should be phrased in such a way that the answers can be evaluated or scored. "Open-end" questions are sometimes used, but they may create serious problems when results are compiled. Some scales are made up of direct questions, with blank spaces for positive or negative answers, as in the following:

Yes	*No*	
____	____	Are promotions fair in this company?
____	____	Do employees here get a fair day's pay for a day's work?
____	____	Do you use the highest level of your skill in your job?
____	____	Are the production standards fair in your department?
____	____	Would you stay here if you could get as much pay elsewhere?
____	____	Are employee suggestions handled fairly?

Multiple-choice questions are more common. In most of them, possible answers permit employees to express degrees of opinions ranging from a strong positive to a strong negative, as is illustrated by the following sample questions:

The organization and planning of work in my department is
(1) excellent (2) good (3) fair (4) poor (5) very poor

My supervisor's understanding of all the work that is done in our department is
(1) excellent (2) good (3) fair (4) poor (5) very poor

The general reputation of the company in the community is
(1) excellent (2) good (3) fair (4) poor (5) very poor

All in all, as a place to work this company is
(1) excellent (2) good (3) fair (4) poor (5) very poor

The people who direct my work tell me whether my work is satisfactory or not
(1) always (2) usually (3) sometimes (4) rarely (5) never

My supervisor is slow to take care of complaints presented to him by employees
(1) always (2) usually (3) sometimes (4) rarely (5) never

My present work suits my particular interests and talents better than any other job I know of.
(1) strongly agree (2) agree (3) undecided (4) disagree (5) strongly disagree

The Company treats its employees better than most other companies I know.
(1) strongly agree (2) agree (3) undecided (4) disagree (5) strongly disagree*

5.2.2.6 Opinions and information. McMurry has distinguished two types of polling procedure. In one, steps are taken to discover the opinions of employees. The other seeks information. He describes the two as follows:

"*Formal* measures of moral include, first, those specifically established by management to obtain static or continuing cross section of employee attitudes. Two methods are now being used by industry to arrive at such a *static* cross section. The first is the employee *opinion poll*. Here a series of multiple-answer type questions is submitted to

* For greater detail, see Benge, *How To Make a Morale Survey;* James C. Worthy, "Discovering and Evaluating Employee Attitudes," American Management Association, *Personnel Series No. 113,* 1947, 13-22; "Experience with Employee Attitude Surveys," National Industrial Conference Board, *Studies in Personnel Policy No. 115,* April 1951.

the employee who is asked to check the answer which most nearly expresses his opinion (e.g., he is asked to indicate whether his working conditions are 'very satisfactory,' 'all right,' 'somewhat unsatisfactory,' or 'very unsatisfactory'). These questions cover such subjects as working conditions, supervision, management policies, employee services, rates of compensation, and attitudes toward the personalities and competence of top management. No writing is required. The employee simply makes a check mark opposite the appropriate response to each question. He is not asked to sign the questionnaire or identify himself in any manner. In this way the identity of each person taking the poll is completely protected. The completed forms are placed in a ballot box and not less than ten ballots go in any one box. Polls of this nature are usually conducted once every one or two years.

"The employee *information poll* provides a second and less direct method by which a measure of employee morale is obtained. Here the multiple-choice question is used to determine what the employee *believes* about the company's ownership, its profits, its history, its product, and what he knows about its employee services, benefits, etc. The immediate purpose, as the name implies, is to check how much the employees actually know about the company. Its importance as a measure of morale lies in the number and nature of the misconceptions it reveals. A poll of this sort should be conducted periodically to be sure that the resultant cross section includes new employees. It provides a reliable check on the effectiveness of downward communication between employees and management." *

5.2.2.7 Improvement and maintenance of morale. To improve morale and to maintain it at high levels, employers undertake a variety of programs. Each program is based on a careful consideration of all the indicators of dissatisfaction and on a determined effort to secure frequent measures of morale. Further steps may be designed to eliminate sources of dissatisfaction and to create a sound basis for high morale.

McMurry has outlined a number of steps designed to improve morale. They include the following:

1. As a first step, it (the management) can insure proper selection and placement of employees. . . .
2. It can establish clear channels of communication *upward*. . . .
3. It can inaugurate a policy of prompt and specific action *on its own initiative*, to correct, wherever possible, any conditions which give employees legitimate grounds for complaint. . . .
4. It can establish clear channels of communication *downward*. . . .
5. It can establish channels for *lateral* (intra- and interdepartmental) communication. . . .
6. It can introduce a program of executive and employee counseling which utilizes the *precinct captain approach* to insure the acceptance of management by the worker.*

5.3 IN-PLANT COMMUNICATION

Problems of motivation and morale are inevitably tied up with the related problem of in-plant communication. Communication failures and inadequacies are widely believed to be close to the heart of motivation problems. Failure to communicate downward and laterally results in misunderstandings and conflicts. Inadequate upward communication allows management to ignore justifiable complaints and criticisms and leads to the accumulation of frustrations and grievances. Current

* Robert N. McMurry, "The Measurement of Employee Morale," *Sixth Annual Industrial Relations Conference*, University of Minnesota Center for Continuation Study, and Industrial Relations Center, 1948, 39-41. Reprinted by permission.

* Robert N. McMurry, "Techniques of Improving Morale," *Sixth Annual Industrial Relations Conference*, University of Minnesota Center for Continuation Study, and Industrial Relations Center, 1948, 49-53. Reprinted by permission.

practice, insofar as it has taken account of these relationships, concludes that in-plant communication should be three-way: upward, downward, and across the lines of the organization.

5.3.1 Communications media. Principal formal in-plant communications media include:

Downward lines:
- Orientation materials
- Handbooks and manuals
- Bulletin boards and posters
- Employee magazines and newspapers
- Financial reports to employees
- Letters to employees
- Pay checks and inserts
- Newspaper advertisements
- Various audio-visual aids—movies, sound-slides, public address

Upward lines:
- Suggestion systems
- Campaigns and contests
- Employee committee systems
- Letters to the editor
- Union publications

Lateral lines:
- Departmental and foremen's meetings and conferences
- Plant bulletins and magazines*
- Collective agreements

5.3.2 Readability problems. One of the reasons why oral communications are widely preferred is that much of the written material prepared for in-plant communication is uninteresting and hard to read. Farr, Paterson, and Stone report that 25 management publications (principally employee handbooks) studied were on the average "fairly difficult," and that 25 union publications studied were "difficult," i.e., harder to read than the management media.* In terms of interest, they found that the management publications scored "mildly interesting," while the union publications scored "dull." †

5.3.3 Auditing communications. In spite of these shortcomings, it is still widely assumed that written media for in-plant communication are effective. Numerous studies have indicated the fallacy of such an assumption. Actually, one of the most important functions of the employment relations staff is the continued auditing of all phases of manpower management, including in-plant communications. Standard tests of readability and interest are now available and may be applied to all types of written communications. Communications "scales" that seek to evaluate the over-all effectiveness of all types of media as well as of specific devices are now in the experimental stage. The

* For detailed discussions of these media, see Yoder, *Personnel Principles and Policies,* Chapter 22; Peter F. Drucker, "Communications—What Are Employees Really Interested In?" *Advanced Management,* Vol. 16, No. 2, February 1951, 7-9; Alexander R. Heron, *Sharing Information with Employees* (Stanford, California: Stanford University Press, 1942), p. 97; Roger M. Bellows, *Psychology of Personnel in Business and Industry* (New York: Prentice-Hall, Inc., 1949), pp. 337-338; Robert Newcomb and Margaret Sammons, "Effective Plant Bulletin Boards," *Industrial Marketing,* Vol. 33, August 1948, 42-43; "Employee Publications," National Industrial Conference Board, *Studies in Personnel Policy No. 31,* 1942; "Employee Magazines," Metropolitan Life Insurance Company, 1944; Robert D. Breth "Trends in the Employee Publications Field," *Personnel,* Vol. 26, No. 6, May 1948, 413-416; *Ten Commandments for a House Organ* (New York: Labor Relations Institute, 1951); Harriet O. Ronken, "Communication in the Work Group," *Harvard Business Review,* Vol. 29, No. 4, July 1951, 109-114; Helen Baker and John M. True, "Transmitting Information Through Management and Union Channels," Industrial Relations Section, Princeton University, 1949.

* James N. Farr, Donald G. Paterson, and C. Harold Stone, "Readability and Human Interest of Management and Union Publications," *Reprint Series No. 7,* Univeristy of Minnesota, Industrial Relations Center, 1950. Reprinted by permission from *Industrial and Labor Relations Review,* Vol. 4, No. 1, October 1950, 88-91.

† See also Donald G. Paterson and James J. Jenkins, "Communication Between Management and Workers," *Journal of Applied Psychology,* Vol. 32, No. 1, February 1948, 71-80; Donald G. Paterson, "Development of a General Information Sheet for Potential Applicants," *Personnel,* March 1948, 317-320.

auditing process should probably give as careful scrutiny to basic communications policy—the objectives of communications—as to the effectiveness of media.*

5.4 EMPLOYEE BENEFITS AND SERVICES

Among the most common of the positive programs undertaken by employers to encourage enthusiastic employee participation are those that seek to provide special benefits and services. Originally, most of these provisions were created by unilateral employer action. Since the beginnings of workmen's compensation and social security, however, more and more public provisions have appeared. Also, with the growth of collective bargaining, many of these services have been brought within the scope of combined union-management sponsorship and administration.

Earlier, unilaterally sponsored benefits often sought to impress employees with the paternalism of employers and were an expression of middle-class humanitarianism. On that basis, they were of doubtful effectiveness in creating or maintaining high morale. More recently, these provisions have come to be regarded as perquisites of the job and added assurances of employee security. As such, although the evidence is by no means clear, they are generally assumed to relieve employees of much worry and concern and thus to encourage fuller and freer interest in the job.

* See "Checking the Effectiveness of Employee Communications," American Management Association, *Personnel Series No. 108,* 1947; Eileen Ahern, "Spotlight on an Unsolved Problem—Communication," *Personnel Journal,* Vol. 29, No. 8, January 1951, 306-307; Jeanne Lauer and Donald G. Paterson, "Readability of Union Contracts," *Personnel,* Vol. 28, No. 1, July 1951, 36-40; E. G. Knauft, "Measured Changes in Acceptance of an Employee Publication," *Journal of Applied Psychology,* Vol. 35, No. 3, June 1951, 151-156; Alex Bavelas and Dermot Barrett, "An Experimental Approach to Organizational Communication," *Personnel,* Vol. 27, No. 5, March 1951 366-371.

5.4.1 Types of services and benefits. The range and variety of specific benefits are very wide. Some of them represent adjustments or conveniences in working arrangements, such as special leave for shopping (for women employees with family responsibilities) and variations in working hours to look after children who spend the day in nurseries and kindergartens. Other arrangements are designed to encourage employee participation in such community activities as Red Cross and community chest campaigns. Sometimes employee publications and training programs (especially those that allow employees to attend classes in colleges, high schools, and vocational schools) are regarded as services. Other principal types of employee services may be outlined as follows:

1. Health services:
   - Physical examinations
   - Plant medical, dental, and optical services
   - Plant nursing services
   - Paid sick benefits
   - Sickness leave
   - Hospitalization
   - Dietetic advice and training
2. Other professional services:
   - Legal aid
   - Recreational direction
   - Counseling
3. Financial services:
   - Insurance (group life, health, accident, disability)
   - Savings associations (credit unions, loan funds, and other similar provisions)
   - Housing aid
   - Transportation facilities
   - Group purchasing arrangements
   - In-plant feeding services
   - Company stores
   - Pensions*

5.4.2 Safety and health. Although the safety program in modern industry pro-

* See also Hubbard C. Capes, "Personnel Practices as Related to Company Size," *Personnel,* Vol. 27, No. 2, September 1950, 121; also Robert D. Gray and Staff, "Survey of Selected Personnel Practices," Industrial Relations Section, California Institute of Technology, 1949.

vides numerous services, it is seldom regarded by either employers or employees as a service or benefit.

Knowles and Thomson have outlined the functions of the industrial health program as follows:

"1. Determine the physical and mental fitness of employees.

2. Maintain a healthy and efficient working force.

3. Conduct health education inside the plant and in the worker's home.

4. Keep records of health and accidents of persons (requiring medical attention) in the employ of the company.

5. Reduce lost time of absenteeism caused by illness.

These functions should be achieved by means of providing the following services:

1. Prehiring examinations and periodic re-examinations for all employees.

2. Correction of physical defects of employees found upon examination.

3. First aid for accidents.

4. Control of occupational health hazards.

5. Provision of adequate emergency dispensaries and hospital facilities.

6. Supervision of sanitary facilities, lunch rooms, and drinking water.

7. Cooperation with family physicians, local hospitals, and clinics as well as specialists.

8. Giving special examinations when needed, such as eyes, ears and teeth, mental tests.

9. Group plans of insurance for hospital and medical service and rendering advice for assistance in securing competent hospital care." *

Organization of medical and safety departments must be adapted to the size of the firm and to the nature of its activities, as must the professional staff † (See Sections 11 and 12.)

Health programs presently include much more than medical and nursing service and appropriate facilities. They frequently arrange for hospitalization of employees (and sometimes their families), surgical benefits, outside medical care, cash aid in sickness, and sick leave. How widespread these provisions have become may be judged from a survey made in 1950 that covered almost 7,000 firms in 12 metropolitan areas. More than three-fourths (75.7 per cent) of these firms reported hospitalization plans, almost half (46.7 per cent) had surgical benefits, 12.7 per cent reported prepaid medical care, 27.9 per cent maintained an organized plan for cash sickness benefits, and 40.7 per cent provided paid sick-leave.*

5.4.2.1 Disability benefits. Since 1942, public provision has been made to alleviate problems of accident and illness. Laws in several states now provide disability benefits. The first of these laws

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* Asa S. Knowles and Robert D. Thomson, *Management of Manpower* (New York: The Macmillan Company, 1943), pp. 45-46. Reprinted by permission.

† See also *Management Almanac*, 1946, p. 175; Industrial Relations Counselors, *Industrial Relations Memo No. 91*, New York, 1947; "Company Medical and Health Programs," National Industrial Conference Board, *Studies in Personnel Policy No. 96*, 1948; C. O. Sappington, "Industrial Health Department Functions and Relationships," Industrial Hygiene Foundation, *Medical Series Bulletin No. 8*, Pittsburgh, 1948; Bernhard J. Stern, *Medicine in Industry* (New York: The Commonwealth Fund, 1946); "Industrial Medical Service —For the Smaller Plants," *Industrial Medicine*, Vol. 15, No. 3, March 1946, 192 ff; Joanna M. Johnson, "The Role of the Nurse in Plant Safety and Health," *Industrial Relations*, Vol. 5, No. 1, May 1947, 22 ff; F. M. R. Bulmer and G. R. McCall, "How the Employer May Evaluate His Medical Service," *Industrial Medicine*, Vol. 14, No. 10, October 1945, 787 ff.

* See Bethel J. McGrath, *Nursing in Commerce and Industry* (New York: The Commonwealth Fund, 1946); "Employee Benefit Plans," Research Council for Economic Security, *Publication No. 69*, May 1950; "Trends in Employee Health and Pension Plans," American Management Association, *Personnel Series No. 118*, 1948; N.A.M. Industrial Relations Department release on "Health and Welfare Plans," December 20, 1946; for an excellent example of such plans, see "Shell Disability Benefit Plan Regulations," Shell Oil Company, January 1, 1950.

was enacted by Rhode Island in 1942. That law requires employers in specified industries to participate in a state fund providing weekly sick benefits. Employees also contribute to the fund, at the rate of 1½ per cent of earnings. Benefits range from $10 to $20 a week. California (1946), New Jersey (1948), New York (1949), and Washington (1949) have provided similar benefits.*

5.4.3 Legal aid. A survey in 1948 found that only 17.7 per cent of some 834 firms regularly provided legal services for both hourly-rated and salaried employees. Such services are more frequently provided for salaried than for hourly-rated employees. Three types of arrangement are found: (1) services provided by the firm's legal department, (2) services made available to employees by "outside" attorneys retained by the employer, (3) "outside" legal services authorized by the personnel or industrial relations department. The first arrangement is the most common.

Such legal aid seeks, for the most part, to assist employees in solving personal problems. It is informal rather than formal; the services do not usually extend to filing suits, representing the employee in extended court proceedings, or drafting lengthy legal papers. Rather, they provide advice for employees on questions of income-tax returns, real-estate transactions, wills, installment-purchase contracts, naturalization procedures, settlement of personal claims, family difficulties, and minor traffic and other offenses.

5.4.4 Counseling. Services performed by counselors have been described as follows:

"Functions of the Counselor

1. In relation to workers

a) Inform workers about services and facilities available to them in the plant or community (such as day care centers, savings and loan funds, rationing boards, housing centers, recreation departments, and social service agencies).

b) Help workers with personal problems which originate outside the plant and which affect their well-being and productivity on the job (arrangements for day care of children, transportation and shopping, housing, medical care, and other domestic and financial problems).

c) Help workers with personal difficulties which cause 'job problems' (such as need to work on a different shift because of home responsibilities; lack of acceptance by his supervisor or fellow workers because of factors such as race, nationality, or personal habits).

2. In relation to stewards, foremen and other management representatives

a) Encourage and participate in programs which train stewards and foremen in 'human relations.'

b) Interpret the effect of production and employment policies on the worker's personal and family life, and the relationship between personal problems and job performances.

c) Inform management of physical conditions within the plant that can be corrected to improve the efficiency and well-being of workers.

d) Upon request, discuss with stewards and foremen the handling of employee 'job problems' affected by personal factors.

e) Upon request advise with stewards and foremen on leaves of absence, transfers, and granting of certificates of availability requested for personal reasons only.

f) Offer the services of the counselors to other in-plant departments (such as medical and safety) in giving workers supplementary interpretation of health and safety measures.

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* For greater detail, see "New Jersey Disability Insurance Program," Washington, D. C.: Department of Labor, Bureau of Employment Security, October 1950; "Compulsory Sickness Compensation for New York State," National Industrial Conference Board, 1947; "Temporary Disability Insurance—Why Coordinate with Unemployment Insurance?" Bureau of Employment Security, U. S. Department of Labor, April 1951; Domenico Gagliardo, *American Social Insurance* (New York: Harper and Brothers, 1949), Part V.

3. General

a) Keep in touch with community agencies to obtain information about existing community resources and to interpret the needs of workers.

b) Promote joint action of community, labor, and management groups to secure needed community facilities and services.

The effectiveness of the counseling service depends largely upon the quality of its direction. The head counselor should (1) plan the program in cooperation with those initiating and sponsoring it, (2) carry out its objectives through supervision and training of counselors and maintenance of relationships with community agencies, (3) report to the sponsoring group, (4) interpret the problem of workers and the needs of the service to in-plant and community groups, and (5) help in forming and modifying personnel policies on the basis of experience with the operation of the counseling service." *

5.4.5 Recreational services. Recreational activities are generally of three major types:

1. Physical or athletic, including bowling, basketball, baseball, softball, golf, tennis, horseshoes, table tennis, volleyball, badminton, archery, hiking, shuffleboard, and similar sports and games.

2. Social, including such games as checkers, chess, bridge, and dominoes, together with dancing, picnics, smokers, and similar affairs.

3. Cultural, including avocations and hobbies, such as crafts, gardening, music, choral singing, orchestras, the arts, painting, sculpture, photography, dramatics, and similar activities.

Facilities for these activities are frequently provided by employers, although they may be supported in part by employee membership fees or, much more frequently, by profits from soft-drink machines, snack bars, and similar vending equipment. If professional services are available, they are usually provided by the employer. Special university training for industrial recreational directors is now available.*

Duggins and Eastwood have outlined the major criteria for evaluating recreational programs. They list the following:

"1. Provide equality of opportunity for all. . . .

2. Provide a wide range of individual choices in different types of activities. . . .

3. Continue throughout the year. . . .

4. Provide equally for both sexes. . . .

5. Encourage family recreation. . . .

6. Utilize fully all existing facilities. . . .

7. Include passive as well as active forms of recreation. . . .

8. Provide activities for different periods of free time. . . .

9. Be related to other programs in the city. . . .

10. Offer possibilities for varying de-

* *A Guide for Establishment and Operation of In-Plant and Community Information and Counseling Services for Workers* (Washington, D. C.: Federal Security Agency, Office of Community War Services, Counseling Committee, 1944), 2-6. See also *The Employee Counselor in Industry* (New York: Metropolitan Life Insurance Company, 1943); Henry Eilbert, "Management Policy Aspects of Employee Counseling," *Personnel*, Vol. 27, No. 6, May 1951, 519-523; Paul S. Burnham and Stuart H. Palmer, *Counseling in Personnel Work: An Annotated Bibliography* (Chicago: Public Administration Service, 1951); Earl M. Bowler and Frances Trigg Dawson, *Counseling Employees* (New York: Prentice-Hall, Inc., 1948); Dugald S. Arbuckle and Thomas Gordon, *Industrial Counseling* (Boston: Bellman Publishing Co., 1949); A. Kraus, "Some Recent Trends in Employment Counseling," *Personnel Administration*, Vol. 9, No. 5, May 1947, 29-31; Nathanial Cantor, *Employee Counseling* (New York: McGraw-Hill Book Co., Inc., 1945); Robert N. McMurry, *Handling Personality Adjustment in Industry* (Chicago: Central Y.M.C.A. University, 1944).

* For greater detail, see Leonard J. Diehl and Floyd R. Eastwood, *Industrial Recreation—Its Development and Present Status* (Lafayette, Indiana: Purdue University, 1945); "Employee Recreation Activities," National Industrial Conference Board, 1949.

grees of skill, aptitudes, and capacities. . . .

11. Encourage individuals and groups to provide their own activities. . . .

12. Furnish outlets for the satisfaction of the desire for social relationships. . . .

13. Recognize the different tastes and interests of the individual. . . .

14. Give people who participate a share in the planning and control. . . .

15. Place recreation opportunities within the financial abilities of all the people. . . .

16. Make possible the wisest use of available funds. . . .

17. Provide outlets for creative expression. . . .

18. Assure safe and healthful conditions for recreation activity. . . .

19. Afford opportunities for developing good citizenship. . . ." *

5.4.6 Insurance programs. Group insurance represents a benefit that has long offered distinct advantages over personal insurance held by the individual employee. Insurance costs can be greatly reduced by "blanket" or group policies. Costs of selling and administering group insurance are much lower than for handling the same number of individual policies. More than 18 million employees are presently covered by almost 50,000 master contracts. The average amount of protection is $2,000.

Current group insurance programs provide several types of policies, of which the most important are "life" insurance (death benefits), accidental death and disability, hospital expense, surgical benefits, medical costs, and annuities. Usual provisions allow an employee to convert his policy to any standard form if he resigns. Benefits may be uniform for all employees or may be graduated according to earnings or length of service. Employees usually become eligible to participate after a short period of service. Coverage is provided without physical examination, and may be continued after retirement. Participation may be optional or may be required of all eligible employees.

Accidental death or sickness insurance provides protection against non-occupational accidents and illness. It is designed to supplement workmen's compensation. Supplementary benefits are generally stated as 50 per cent of usual wages or salaries, with specified maxima. Hospital, surgical, and medical benefit policies provide appropriate compensation.

Provision of group annuities leads these insurance provisions directly into the pension field. Group annuities provide stated pension benefits for participants, thus creating a pension supplementary to that which may be available through the federal social security program.

Costs of insurance programs may be borne jointly by employers and employees ("contributory" programs) or may be paid entirely by employers. Earlier programs were generally contributory, but in recent years many programs have been negotiated and are non-contributory. Costs vary according to the types of coverage provided and the ages of employees. Life insurance, with a normal age distribution of employees, costs about $1 per $1,000 coverage per month; accidental death and dismemberment about 10 cents; accident and sickness about 60 cents; hospital and surgical benefits about 50 cents. Annuity costs vary directly with the ages of those for whom the benefits are provided.*

* G. Herbert Duggins and Floyd R. Eastwood, *Planning Industrial Recreation* (Lafayette, Indiana: Purdue University, Division of Physical Education for Men, 1941), 31-33. Reprinted by permission.

* For greater detail, see F. Beatrice Brower, "Group Accident and Sickness Insurance," *Management Record,* Vol. 12, No. 1, January 1950, 3; also her "Life Insurance for Retired Employees," *Management Record,* Vol. 12, No. 4, April 1950. 130-131; "Company Group Insurance Plans," National Industrial Conference Board, *Studies in Personnel Policy No. 112,* 1951; for illustrative plans, see "Shell Income Protection Insurance," Shell Oil Company, 1951; *Your Insurance* (Grand Rapids, Michigan: American Seating Company, 1950).

5.4.7 Savings, loans, and credit. Provision may be made for aiding employees to save and invest through savings and loan associations, opportunities to purchase stock (both of the parent concern and of others), arrangements for financing homes, and facilities for making smaller loans to employees. Advice and assistance may be given to employees who are seriously in debt. In some situations, employees may form their own credit union, with or without the provision of office space and clerical assistance by the employer. Credit unions are small-loan associations, designed to accept savings and to make small loans at low cost. Regulated by state and federal governments, some 5,000 state associations and 4,600 federal credit unions are active. More than four million employees are members. Loans amount to almost a billion dollars. Members must subscribe for at least one share of stock, usually at a par value of $5. Shares may be purchased on an installment basis. The maximum number of shares held by an individual may be restricted. Funds thus provided are used in making loans to members, and earnings are distributed as dividends or are allowed to accumulate as surplus. These associations are in effect small banks and are subject to banking laws.*

5.4.8 Other financial services. Numerous other services have been established, either unilaterally or by agreement with employees, to provide economies for employees. No complete list is available, for the combinations and complexities of these devices are almost endless. Among the more common services of this type, however, are:

5.4.8.1 Food services. In-plant cafeterias and lunch rooms, combined with stationary and portable snack bars, lunch carts, and other similar arrangements, make it possible for employees to secure warm, nourishing food for one or more meals without leaving the premises. Such facilities may be managed directly by employers, by a committee or association of employees, or by an outside agency under contract. They usually require substantial subsidization by the employer.*

5.4.8.2 Cooperative purchasing. Employees are frequently given opportunities to save by purchasing products, materials, and services through the firm's purchasing office. Such arrangements are becoming less common, in part because of opposition from local merchants and in part because of restrictions imposed by wholesalers and jobbers. On the other hand, the practice of allowing employees discounts on material purchased from the employer is well established, particularly in retail stores and in manufacturing concerns whose products are suitable for personal use.

5.4.8.3 Transportation. In many current situations, employees use private automobiles to get to work. Under these conditions, parking may become a serious problem. Provision of adequate, convenient parking space is increasingly common. In addition, if plants are located outside city limits or if established streetcar and bus service is inadequate, employers have provided company busses. In other arrangements, working hours are staggered to reduce crowding on public transportation facilities, and employers provide assistance in organizing car pools and similar cooperative transportation.

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* See Arthur H. Hern and Leonard G. Robinson, *A Credit Union Primer* (New York: Russell Sage Foundation, 1914); see also frequent reports on credit-union membership and financial statistics in the *Monthly Labor Review*; also Roy F. Bergengren, *Credit Union—North America* (Kingsport, Tenn.: Southern Publishers, 1940).

* For details, see "Industrial Feedings: Luxury or Necessity?" *Modern Industry*, Vol. 16, December 1948, 54-56; *Lunchrooms for Employees* (New York: Metropolitan Life Insurance Company, 1945); "The Feeding of War Workers" (Bibliography), Industrial Relations Section, Princeton University, March, 1943; "Nutritional Programs for Industrial Employees," Industrial Relations Section, Princeton University, December, 1942; "Setting up the Committee on Food," *Labor and Management News* (War Production Board), May 27, 1944.

5.4.8.4 Housing. Efforts have frequently been made to aid employees in building or buying homes. Building and loan associations have been sponsored for this purpose. In other situations, employers have sought to attract and hold employees by providing rental housing. Some concerns have developed entire communities, building homes and renting them to employees. In some localities no other housing is available to employees. Even when no homes are provided, a housing service may maintain lists of homes for rent and for sal, and may aid employees in finding, renting, purchasing, and financing homes. Employees have sometimes regarded housing provisions as a means of spying on them. To reduce criticism and to improve acceptance by employees, housing developments may be managed by a joint employer-employee committee. Housing may be financed directly by the employer, or he may guarantee or otherwise sponsor an arrangement with a local building and loan association.

5.5 ECONOMIC SECURITY

Numerous arrangements, both public and private, currently seek to provide greater economic security for employees and thus to free their minds from financial worry. All the employee services and benefits mentioned in the preceding section have that objective in the background.

Principal hazards to economic security include: (1) incapacitation—disablement by accident or illness, with accompanying loss of employment and earnings; (2) old-age dependency—enforced retirement from the job without adequate means for support; and (3) unemployment—loss of job and earnings. These categories are not entirely exclusive, since incapacitation may be caused by old age, and unemployment may reflect either old age or incapacity or both. And all three involve the hazard of losing a job and earnings. They are all job-connected or job-related insecurities.

5.5.1 Health hazards. Principal safeguards against economic insecurity resulting from incapacitation include health and welfare programs, workmen's compensation, and disability insurance. The first may be provided on a unilateral basis or by joint employer-union agreement as a benefit or service (Art. 5.4.2).

5.5.1.1 Workmen's compensation. Legislation providing for workmen's compensation benefits covers various types of incapacitation. Protection may be limited to the results of accidents, or it may extend to what are regarded as work-connected disease and illness. "Schedule" coverage limits benefits to stated types of illness; "full" coverage allows benefits for all job-connected disability. The provisions and variations in state legislation are indicated in Fig. 4.28.

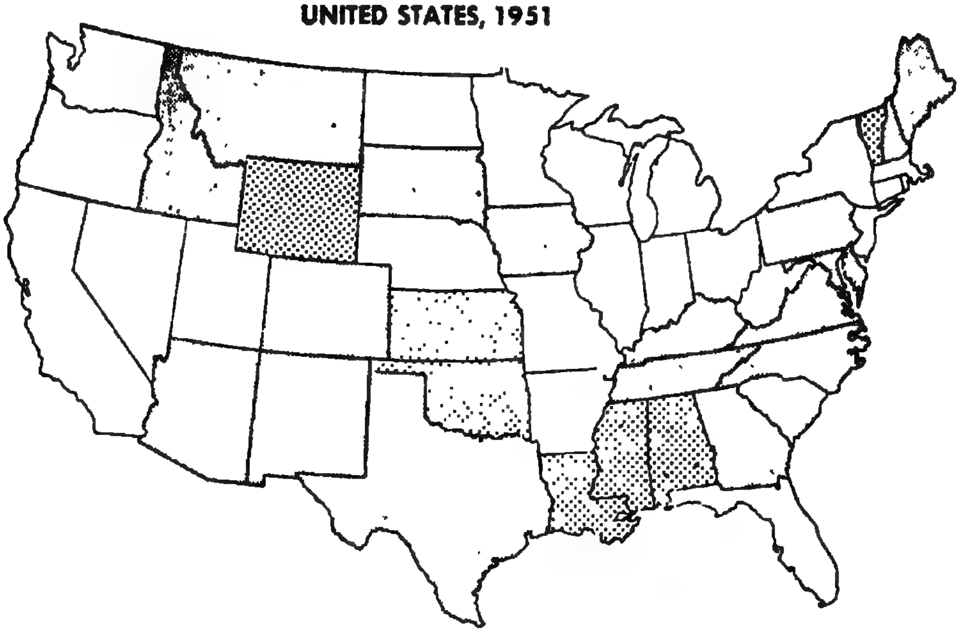
Some states allow private insurance; others require insurance in public funds. Special provision is made for second injuries to employees by relieving employers of the special financial obligations arising out of such cumulative accident experience.*

5.5.2 Old age. The hazard of dependency in old age has received widespread attention since public awareness of our aging population became general. The migration of older persons to various sections of the nation has caused special concern. The problem is complicated by the tendency to exclude older persons from the labor force.

5.5.2.1 Public provisions. The 1935 Federal Social Security Act, as amended, provides two types of help for older persons: (1) old-age assistance on the basis of need, and (2) pensions and benefits based on contributory participa-

* See *Tables of Working Life* (Washington, D. C.: Bureau of Labor Statistics, August, 1950); Frank S. McElroy and Alexander Moros, "Illness Absenteeism in Manufacturing Plants, 1947," *Monthly Labor Review*, Vol. 67, No. 3, September 1948, 235-240; *Accident Facts*, published annually by the National Safety Council; Rollin H. Simonds, "Estimating Industrial Accident Cost," *Harvard Business Review*, Vol. 29, No. 1, January 1951, 107-113

CHART III OCCUPATIONAL DISEASE COVERAGE UNITED STATES, 1951



Reproduced by permission from Louise K. Steiner, "Recent Trends in Occupational Disease Legislation," University of Illinois, *I.L.I.R. Publications, Bulletin Series*, Vol. 5, No. 1, May, 1951.

FIG. **4.28** OCCUPATIONAL DISEASE COVERAGE, BY STATES.

tion in the plan. Financed by a special payroll tax, the pension program applies to both employees and self-employed, with stipulated exclusions. Benefits protect survivors as well as covered employees.

5.5.2.2 Private plans. Private pensions may be provided by a plan initiated and maintained by an employer, or they may be established by collective bargaining. Employees may or may not be required to contribute to them. As the limits of public provisions have become more generally recognized, demands for supplementary private pensions have increased. Employers may have contributed to these demands by their generous provision of retirement allowances to presidents, directors, managers, and others. Many negotiated pensions are now integrated with public provisions. They stipulate that private benefits shall be in an amount necessary to provide a specified total.

Sound policy for pension programs must be based on Treasury Department regulations. Treasury rules require, for example, that a plan must not discriminate against any group of employees, and that benefits must be available to all on an equal and reasonable basis if contributions to these plans are to be eligible as tax deductions.*

5.5.2.3 Compulsory retirement. Many

* See Jule J. Justin, "Pension Plans—Check List for Administrators," *Harvard Business Review*, Vol. 28, No. 6, November 1950, 114-122; Carroll W. Boyce, *How To Plan Pensions* (New York: McGraw-Hill Book Company, Inc., 1950); Sumner Slichter, "Social and Economic Impact of the Pension Trend," American Management Association, *Personnel Series No. 113*, 1950; Hugh O'Neill, *Modern Pension Plans* (New York: Prentice-Hall, Inc., 1947); "Handbook on Pensions," National Industrial Conference Board, *Studies in Personnel Policy No. 103*, 1950; Edward L. Schwartz, "Pension and Retirement Programs," *Labor Law Journal*, Vol. 1, No. 1, October 1949, 25-32. *Pension and Profit Sharing Service*, Prentice-Hall, Inc., 70 Fifth Ave., New York.

of the current pension provisions in private plans require that pensioners be retired. And the public program restricts amounts that may be earned by pensioners. The result is to encourage a waste of manpower that could, at least in part, pay its own way. Improvements in health have resulted not only in longer lives but in lesser incapacitation of older persons.

A movement against compulsory retirement is in process. It seeks to encourage the continued active participation of oldsters and thus to provide them with additional support. In essence, the movement seeks to assure that older persons will not retain control of policy-making functions or hold jobs that they cannot perform efficiently, but that they will be permitted to work so long as use can be made of their services.

Specific policies and programs designed to attain these results vary. For officers and management personnel, a retirement age may be set, after which employment is optional. If the retiring individual is able to continue work, he may be rehired on either a part- or full-time basis. He will, however, generally be relieved of any managerial responsibility. He will not usually receive his pension during continued employment, although there are exceptions to this rule.

Non-managerial employees may be offered a similar option. They may be re-employed after they reach retirement age in whatever jobs are suitable. Re-employment is usually in lieu of pensions, which will be paid whenever no further employment is possible.*

5.5.3 Unemployment. Unemployment is caused by various factors. Fluctuations in the rate of business activity occasion two types—seasonal and cyclical. Changes in the processes and methods of operation create technological unemployment. Frictional unemployment arises from the unavoidable process in which free employees seek improved opportunities by changing jobs. "Personal" unemployment reflects individual characteristics that tend to prevent stable employment. Various devices have been developed to aid employees in meeting the insecurity that arises out of each of these types of unemployment.

5.5.3.1 Dismissal compensation. Severance allowances, sometimes called dismissal compensation, may be provided to facilitate transfers to new jobs. Such allowances, generally proportioned to rates of pay and length of service, may amount to several hundreds or thousands of dollars. They permit the employee to look around for a satisfactory position, and reduce the necessity for immediate acceptance of a new job. In another similar arrangement, employees are advised of their prospective displacement but are allowed to remain on the payroll for a stated period while devoting full time to job-seeking.

5.5.3.2 Stabilization programs. Employers have developed a number of techniques designed to regularize or stabilize employment opportunities. They study past patterns of expansion and contraction and plan operations to insure stability throughout a year or a longer period. They seek to secure advance orders, stimulate slack season sales, develop new markets, produce for stock, coordinate production and sales, shift employees to maintenance and repairs, diversify production, facilitate interdepartmental transfers, and employ other measures to smooth fluctuations in employment.*

5.5.3.3 Unemployment compensation. Public protection against unemployment is provided by the Social Security Act of 1935. This act created a joint federal-state program. Taxes are collected by both federal and state governments, under an arrangement that permits an

* See, in this connection, Richard C. Wilcock, "Who's Too Old to Work?" University of Illinois, *I.L.I.R. Publications, Bulletin Series,* Vol. 4, No. 3, September 1950; Harland Fox, Theodore R. Lindbom, and C. Harold Stone, "After Age 65—What?" *Personnel Journal,* Vol. 30, No. 5, October 1951, 181-187.

* For details on these programs and references to reports on them, see Yoder, *Personnel Management and Industrial Relations,* Chapter 18.

employer to offset state tax payments against federal tax liabilities. State tax provisions provide for adjustments in tax rates, so that an employer who has few unemployed charged to his account pays reduced taxes. Tax savings thus secured are also deductible against federal tax liabilities. Federal legislation sets the basic pattern of coverage, although details are left to state plans. Public employees, employees working in religious, educational, and charitable organizations, agricultural employees, and domestic servants are excluded from coverage under federal law.

All disbursements are made through state agencies, and state laws set the level and maximum lengths of benefits, eligibility for benefits, and other similar provisions. Coverage differs from state to state; some states include all establishments, while others include only those with a specified minimum number of employees. Similar variation appears in minimum and maximum weekly benefits, length of benefit periods, and eligibility for benefits. States have also developed different rules for the "suitability" of jobs offered to the unemployed, and for many other details of compensation practice and procedure.

5.5.3.4 Guaranteed employment. During World War II, an investigating committee created by the Office of War Mobilization and Reemployment studied possibilities of making wider provision for guaranteed employment. In 1947, the committee reported, describing 196 active and 62 discontinued plans for which information could be found. Included were such widely discussed arrangements as those of Procter and Gamble, the George A. Hormel Company, and the Nunn-Bush Shoe Company.

The study shows wide differences in the proportions of employees that are covered by the various plans. Employees establish eligibility through length of service. The number of weeks for which employment or wages are assured is not uniform. Some plans guarantee only a proportion of weekly wages. Costs have varied widely. Estimates of full-coverage costs in hypothetical firms over a four-year period vary from 1.3 per cent of annual payrolls to 20 per cent.

The committee concluded that a combination of (1) unemployment compensation, (2) flexibility in hours (to be facilitated by permitting overtime without penalty in stated periods), and (3) guarantees of minimum wages or employment is feasible and promising.*

6. EMPLOYMENT RELATIONS RECORDS, REPORTS, AND RESEARCH

Developing and maintaining appropriate records, preparing reports on the planning and operation of the program, and conducting continuous research studies are important and related responsibilities of the employment relations staff.

6.1 AUDITING THE EMPLOYMENT RELATIONS PROGRAM

Record-keeping, reporting, and conducting research reflect the elementary responsibility of the employment relations staff, to audit, review, and appraise the whole program. In the modern industrial organization, all staff members have planning, counseling, and reviewing functions. They must review current programs, to discover how well they carry out the stated objectives or policies of the organization. Then, they modify programs to make them more effective.

6.1.1 Employment relations policy.

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* See "Guaranteed Wage or Employment Plans," Bureau of Labor Statistics, *Bulletin No. 906*, 1947; "Guaranteed Wage Plans in the United States," Bureau of Labor Statistics, *Bulletin No. 925*, 1947; A. D. H. Kaplan, *Guarantee of Annual Wages* (Washington, D. C.: The Brookings Institution, 1947); Joseph L. Snider, *The Guarantee of Work and Wages* (Boston: Harvard University Graduate School of Business Administration, 1947); "Guaranteed Employment and Wages Under Collective Bargaining," *Monthly Labor Review*, Vol. 70, No. 1, January 1950, 26-33.

Such a review begins by evaluating policies or goals. The staff is not, of course, formally responsible for adopting and establishing policy. It may, however, suggest and formulate appropriate policy and maintain a continuing check on current policy to be sure that it is sound. Employment relations policy extends to every aspect and function of employment. It may be unilaterally determined, in whole or in part, by the employer in the top echelon of the line organization, or it may be established in large measure through collective bargaining.

6.1.1.1 Range of policies. Policy on all manpower management functions should be established, communicated, and interpreted. A convenient check list, indicating the wide range of major subjects to be included, follows:

Check List on Labor Policies

- Employment practices, including
  - sources of employees
  - physical examinations
  - nondiscrimination
- Training provisions
- Placement practice
- Collective bargaining
- Wages, including
  - comparisons with prevailing wages
  - job evaluation, job rating
  - incentive wages
  - stabilized earnings
  - profit-sharing
- Hours, including
  - overtime
  - double time
  - holidays
  - night-shift premiums
  - down time
- Working conditions, including
  - accident prevention
  - occupational disease hazards
  - promotion and transfer
  - stabilizing employment (intra-plant)
  - layoff, discharge
  - vacations
  - release of employees
  - leave of absence
- Grievances
- Employee suggestions and inventions
- Risk protection, including
  - group life insurance
  - retirement
  - hospitalization
- Services for employees, including
  - loan funds
  - legal aid
  - lunchrooms and cafeterias
  - employee savings
  - employee stock ownership
  - employee housing

6.1.1.2 Written policy. In most current practice, policy statements are written to facilitate their communication and understanding throughout the organization. If they are not written, the administrators may not have a uniform understanding of established objectives, and disorganization and dissatisfaction may result among employees. Written statements of policy developed through collective bargaining are usually distributed to all covered employees and all supervisors.

6.1.1.3 Interpretation of policy statements. Employment relations staff members must usually explain and interpret current policy to insure clear and uniform understanding throughout the organization. To help them in this task, they may participate in top-level discussions of unilaterally determined policy Similarly, they may participate in union negotiations. They may present their interpretations in writing or orally at meetings held for that purpose, or both practices may be necessary.*

6.1.2 Periodic audit. As a supplement to continuous review and appraisal, many firms and agencies use a periodic over-all audit of manpower policies and practices, similar to the annual audit of financial activities. It may be an internal audit undertaken by regular staff personnel, or an external audit performed by an outside agency.

The range of policies and practices to be covered in such an audit varies with the nature of the enterprise. There are, however, several model auditing schedules that suggest the scope and detail.

* See Lawrence A. Appley, "Essentials of a Management Policy," *Personnel,* Vol. 23, No. 6, May 1947, 430-436; "Written Statements of Personnel Policy," National Industrial Conference Board, *Studies in Personnel Policy No. 79,* 1947; *The Way We Work: A Guide to Personnel Policy* (Lowland, Tennessee: American Enka Corporation, 1951).

WORKSHEET (CONTINUED)
3.00 EMPLOYMENT

3.01 FIVE-YEAR RECORD

YEAR	MONTH											
	J	F	M	A	M	J	J	A	S	O	N	D

3.02 MONTHLY BY DEPARTMENT

DEPT	MONTH												AVE.
	J	F	M	A	M	J	J	A	S	O	N	D	

3.03 LONG TERM HIGH ________ VARIATION
LOW: ________
CAUSES: ____________________

3.04 PRACTICE

✓	ITEM	COMMENT
	CENTRAL P O	
	INT-DEP TRANS	
	STOCKING	
	UNION COOP	
	HOUR-SHIFT VAR	
	CONTR DEMAND	

Yoder, *Personnel Principles and Policies*, p. 27.

FIG. **4.29** PORTION OF WORKSHEET, GENERALIZED EMPLOYMENT RELATIONS AUDIT.

A thorough audit checks on both policy and practice in every aspect of the industrial relations program, including job analysis and job descriptions; recruiting and checking of sources; selective techniques and devices; applications of wage policy; the rating program; the handling of suggestions and grievances; the operation of transfer and promotional practices; maintenance of specific working conditions, including hours, employment stability, light, heat, and sanitary conditions; employee services and retirement program; enforcement of plant discipline; maintenance of employee morale; collective bargaining; the administration of collective agreements; and other phases of a broad industrial relations program.

No uniform audit is applicable to all situations. Figure 4.29 presents a section of a comprehensive outline used to provide a general audit of an entire industrial relations program.

The auditing of industrial relations programs is still handicapped by the limited number of accepted and "standardized" bench marks. "Normal" or "reasonable" standards with respect to policies and performance must be estab-

lished. Much current research has this purpose. Employment relations audits provide the raw material and information with which research must deal and on which it must depend. Using these facts, research provides additional bench marks for future audits.*

6.2 EMPLOYMENT RELATIONS RECORDS

Records are written accounts of facts or events. They summarize in written or other permanent form certain facts of sufficient importance to be remembered or recalled at some subsequent time. A *report* differs from a record in that it is designed to give information about or to explain facts and events, rather than simply to preserve this information. Thus, a report on recruitment summarizes and describes how many and what kinds of persons have been hired in a stated period. It may also note the special circumstances that justified such activity or the special problems involved in carrying it on. Reports usually cover a stated period; they bring the receiver up to date; they "report" to him.

Records and reports, although distinguishable, are closely related. Reports are often made to create a record. They are frequently conserved as records. Records sometimes serve as reports, as when an interviewer's notes are transmitted to a foreman to advise him on hiring a particular candidate. Moreover, reports are frequently built up from records. Reports may be largely or entirely composed of data first written into personnel records.

6.2.1 Types of employment relations records. Records are maintained for each of the major employment relations functions. Although their variety and range reflect varying individual policies and programs, the following list includes the principal types:

* See Neal E. Drought, "Techniques of Measuring Personnel Effectiveness," and L. E. Schmidt, "Methods of Evaluating a Personnel Program," both in "Measuring Results of Personnel Functions," *Personnel Series No. 111* (New York: American Management Association, 1947), pp. 16-22 and 23-31; Eugene Benge, *Audit Your Personnel Program* (Chicago: Benge Associates, 1944); C. W. Lytle, "An Audit for Wage and Salary Administration," *Personnel,* Vol. 23, No. 4, January 1947, 273-277; Metropolitan Life Insurance Company Policy Holders Service Bureau, "Outline of a Personnel Audit," 1947.

PERSONNEL RECORDS

Manpower management function	*Records*
1. Job analysis, description.	Job description and specification Employee specification Employee job statement Time schedules for jobs Costs of job analysis Notice of vacancy Job breakdown sheet
2. Recruitment	Manning tables and replacement tables Stuffing schedules Applicant appointments Mail applications Requisitions for personnel Application and registration forms Prospect card Qualifications record Skill index
3. Selection and placement	Weighted application blank Interviewer's check list Information on citizenship Interviewer's rating scale Systematic and patterned interview records

PERSONNEL RECORDS (*Continued*)

Manpower management function	*Records*
	Employment history form Educational history Military service record Change of address card Change of marital status card Request for information from references (a) written (b) telephone (c) special for schools Request for medical examination Employee introduction card Notice to payroll department Patent waivers Medical report Test score profile Application for security bond New employee progress report Contract of employment Appointment on employment notice Report or probation
4. Training	Employee training record Training time table Request for tuition refund Certificates and diplomas Grade reports Apprenticeship agreements
5. Wage and salary administration	Application for salary increase Nature of salary change Time record or clock card Change of rate notice Yearly earnings record Overtime authorization Overtime pass Meal voucher Job evaluation schedule Withholding certificate Social security information card
6. Personnel rating	Rating scales Employee rating record
7. Promotion, transfer, and leave	Seniority record Employee review record Request for transfer Notice of transfer Decision on salary review Notice of promotion Request for leave Certificate of management
8. Employee services	Application for benefit association Request for group life insurance Request for refund Application for hospitalization Transportation survey form Authorization for deductions Vacation record

PERSONNEL RECORDS (*Continued*)

Manpower management function	*Records*
9. Health and safety	Attendance record Accident report Sickness, illness reports Absence because of illness Notice to physician Physician's report Medical history Notice of permanent disability Proof of death Permit to return to work Time losses—accidents
10. Discipline and separation	Disciplinary action report Stop or termination notice Final wage payment notice Report of separation Notice of dismissal Exit interview Resignation Layoff slip Warning notice Turnover report Released employee rating Departmental release Notice of supervision
11. Morale measurement and maintenance	Grievance report Grievance appeal notice Morale questionnaire Sociometric ratings Counselor's report Suggestion blanks
12. Collective bargaining	Notice of interpretation or modification Notice of arbitration

6.2.2 Record forms. To aid in preparing and maintaining appropriate records, firms and agencies—as well as private consultants and the public employment service—have developed numerous record forms. Some of these forms reflect little thought or experimentation; others reflect much greater care. Space does not permit their reproduction here, but numerous examples are readily available.*

* See Yoder, *Personnel Principles and Policies*, Chapter 29; also *Personnel Management and Industrial Relations*, Chapter 23; Eileen Ahern, *Handbook of Personnel Forms and Records* (New York: American Management Association, 1949); Dale Yoder, "Interpretation of Personnel Reports and Statistics," American Management Association, *Personnel Series No. 100*, 1946; "Forms, Records and Reports," Minneapolis Civic and Commerce Association, March 18, 1935; *The How and Why of Pay Roll Records* (Tulsa, Oklahoma: Ross-Martin Company, 1946).

6.3 EMPLOYMENT RELATIONS REPORTS

Employment relations staff members prepare numerous reports for the information and assistance of the line or operating organization, and for the use of top management in making decisions on major employment policy. Reports cover each of the major employment relations functions and the progress of the program as a whole.

The importance of these reports probably cannot be overstressed, although in some quarters it has become established dogma that a program dealing with hu-

man relations in employment cannot be fairly or accurately described in written words and that its intangible value and contribution defy reporting. Advocates of this viewpoint insist that any report that attempts to put down in black and white either the objectives or the accomplishments of such a program must be misleading. This position has tended to prevent attempts at regular reporting. It has also tended to prevent full understanding of the employment relations program by those who should implement and support it. As a result, employment relations staff members may—and frequently do—express their concern about the failure of top management and line operators to understand and support the employment relations program. The only way to break this vicious circle is to circulate effective reports that accurately describe the objectives and accomplishments of the employment relations program.

6.3.1 Special reports. From time to time, the employment relations staff—either upon its own initiative or upon the request of operating divisions—prepares special reports. Line divisions may ask for reports on the operation of special programs or phases of the current program. Such reports, for example, may summarize experience with wage surveys maintained by the organization or by an association of which the firm is a member. They may assess experience with certain tests used in selection, or with the personnel rating procedure, or with current training programs, or with the preparatory work undertaken as a basis for collective negotiation of a new labor contract. Similarly, the line may ask for reports on the operation, in similar circumstances, of programs presently under contemplation—rating, training, selection, compensation, in-plant communications, or others. Employment relations staff members must be prepared to develop special reports on any subject falling within the area of their special competence.

Special reports may also be prepared on the initiative of the staff for the information of line operators. Such reports form the basis for recommendations of change in policy and program. For example, the staff may report on the results of an experiment with a new type of training or on current developments in union negotiations, or on recent changes in legislation affecting employment and their implications for firm policy and practice. To an alert employment relations staff, such reports are the ideal means of laying a foundation for continual improvement in policy and practice.

6.3.2 Periodic reports. In many organizations, the employment relations staff prepares regular reports each month. These reports summarize both the current experience of the organization in its employment relationships and the significant developments in the field outside the particular firm or agency.

A periodic report on in-plant programs provides an opportunity of educating all levels of management and supervision—and employees as well, if it is given broad circulation in full or abbreviated form—on the purposes and accomplishments of the entire manpower management program and especially on the activities of the employment relations staff. If properly used, the periodic report can create and maintain a general understanding of the whole program that will insure its approval and support throughout the organization.

In the best current practice, periodic reports include established sections on which a comment is included in each regular issue. One report, for example, provides a brief paragraph on each of the following subjects:

1. Recruitment, selection, and employment
2. Training
3. Promotions, transfers, and separations
4. Health and safety
5. Employee services
6. Morale
7. Wages and earnings
8. Collective bargaining
9. Industrial relations research

Many reports preface these sections with a brief résumé of significant developments, both in-plant and out-plant. They may discuss, for example, the in-

stallation of a new publication or training program, and report briefly on the progress of negotiations in a related firm or industry. By arousing the interest of operating personnel, these résumés encourage them to study the ensuing report on local developments and activities.

6.3.3 Statistical reports. Not all the current activities and developments in the employment relations field can be described in statistical and quantitative terms. A considerable portion of any periodic report must be descriptive and qualitative. On the other hand, much of the current program should produce meaningful statistics, which have a special appeal to many line operators. Moreover, since statistics are useful in research, periodic reports may well include a regular statistical section in which quantitative aspects of the employment

TABLE 4.9 STATISTICAL SERIES TO BE INCLUDED IN THE PERIODIC EMPLOYMENT RELATIONS REPORT*

Function	*Items for monthly report*
Recruitment	Numbers of applicants by source and by means of recruitment Costs of recruitment per applicant
Selection and Placement	Numbers interviewed Numbers tested Placements Costs per placement
Training	Numbers in training, by type of training Numbers admitted to training, by type Numbers finishing training, by type Average length of training period, by type Costs of training, by type
Promotions	Numbers promoted Numbers demoted
Transfers	Numbers transferred, by type of transfer
Morale Maintenance	Absence rates Tardiness rates Grievances filed Grievances settled by level of settlement Counseling interviews Suggestions received Suggestions accepted
Discipline	Disciplinary actions, by type
Health and Safety	Visits to medical service Lost time by illness Accidents, by department Lost time from accidents
Employment	Numbers employed Hours worked New hirings Layoffs Permanent separations, by types
Wage and Salary Administration	Average wages Average weekly earnings Average salaries New rates established

* From Yoder, *Personnel Principles and Policies*, p. 554.

relations program are systematically summarized and compared with the data of earlier reports.

Table 4.9 outlines the nature and variety of statistics that may be included in a statistical report. It is by no means all-inclusive. Numerous additional series will suggest themselves to those familiar with an individual employment relations program.

6.4 EMPLOYMENT RELATIONS RESEARCH

In the years since World War I, interest in employment relations research has grown continuously. Further impetus was provided by World War II, when manpower shortages were a major problem for all warring nations. At the present time, employers, employees, and unions are well aware of the possible individual and social gains to be won through research. Many firms have allocated increasing portions of their annual budgets to new or expanded research divisions. International unions and state and city federations and councils have added research units to their central office staffs.

The need for understanding how human beings react in a variety of employment situations and relationships is clearly evidenced by the serious conflicts, ineffective teamwork, and by the waste of human resources in modern societies. Research can discover how and why waste of manpower resources occurs. Effective allocation, utilization, and conservation of manpower resources depend on an understanding of the complicated principles of human behavior. The present need is for demonstrated principles of manpower management and their widespread recognition and understanding. Such principles can be verified, checked, and established only by study and research. Research is a conscious, planned effort to secure facts and to describe relationships as a basis for fuller understanding. It is a planned, purposive study and analysis of human behavior in employment relationships. Although it may have obvious and "applied" objectives or purposes, in general it aims at prediction and control.*

6.4.1 Problems and hypotheses. Employment relations research is not unusual or distinctive. Like projects in other staff divisions, it seeks facts and relationships in employment that have implications for the more effective practice of manpower management. "Facts" represent conditions or circumstances that have been checked and verified—as distinguished from impressions and casual opinions based on unplanned observation and possible prejudice. "Relationships" represent consistent associations or sequences—presumably based on direct or indirect cause and effect—that can be depended on to recur and that provide a basis for prediction and control.

Research is a purposive search for facts and relationships, planned and conducted to answer significant questions. These questions may be stated either as problems to be solved or as hypotheses to be tested. Some problems involve public policy—what societies should do or seek. Others provide data that may help in formulating sound policy. They discover, for example, how men find jobs. Knowing how jobs are found, societies can better decide what to do about employment offices or discrimination in hiring.

6.4.2 Applied, basic, and pure research. Research projects can be classified on the basis of the applicability of their findings. The usefulness of some studies is limited to specific employment relationships and immediate, practical problems. Such studies represent "applied" research. Other studies are useful in a wide variety of social and economic situations, many of which may lie outside the fields of manpower marketing and management. For example, the implications of research into basic human drives and economic motivations

* See Wilson Gee, *Social Science Research Methods* (New York: Appleton-Century-Crofts, Inc., 1950), p. 195; W. I. B. Beveridge, *The Art of Investigation* (New York: W. W. Norton & Company, Inc., 1951), Chapter IV.

are by no means restricted to a particular firm, time, or even to relationships growing out of employment. Such studies are "basic." Still others, described as "pure" research, investigate fundamental processes of human behavior without reference to their applicability.

6.4.3 Co-disciplinary studies. The applied science of manpower management is related to the social sciences or disciplines—economics, psychology, sociology, and others—somewhat as medicine and biology are related, or medicine and chemistry. Many of the problems studied in employment relations research fall naturally into one or another of these fields—they are economic or psychological or sociological problems, for example. On the other hand, many of the problems of manpower management involve complex behavior and suspected relationships that cross disciplinary lines. An effective attack on such problems may require the combined experience and understanding of several disciplines.

Thus, employment relations research is both narrower and broader than each of the various disciplines that seek to explain human behavior. On the one hand, it seeks answers to more limited and more narrowly defined questions than those considered by the "supporting" sciences. On the other hand, many significant problems in employment relations extend beyond the limits of any single discipline. Just as medical research seeks to discover how to make or keep men well, employment relations studies are undertaken to find out how best to allocate, utilize, and conserve our resources of voluntary employees. And just as medical research problems may involve processes that reach into chemistry, biology, and physics, so the problems of industrial relations research may reflect composites of economic, psychological, and sociological or other processes and require a co-disciplinary approach.

6.4.4 Types of studies. Several types of research studies can be distinguished. Most common are:

6.4.4.1 Logical studies, which seek to state and check hypotheses by deduction, reasoning from the general to the specific. They attempt to apply established generalizations to specific situations. They may, for example, apply a *principle* of economics or sociology to a situation arising in employment.

6.4.4.2 Historical studies, which seek to trace current situations back to their beginnings, looking for explanations of present behavior in the historic development of firms, unions, communities, and their interrelationships.

6.4.4.3 Individual case studies. These have been among the most prominent projects in the field. They do not differ sharply from historical studies, but they focus attention on a single situation, without reference to "outside" influences or other similar "cases."

6.4.4.4 Surveys. Surveys are purposive and planned collections of data from various sources. Wage surveys are typical. Surveys provide primary data that are then analyzed in terms of predetermined hypotheses or questions.

6.4.4.5 Statistical studies. Statistical studies involve the collection, classification, analysis, and interpretation of quantitative data. Of obvious applicability in empirical research, they provide generalized measures of data and enable the researcher to calculate probabilities based on accident or chance.

6.4.4.6 Experimental studies. The experimental method manipulates factors and observes and evaluates results. It is "observation under controlled conditions." Although it is often asserted that experimental methods are not applicable in the social sciences, employment relations research frequently employs this technique. For example, an experimental situation is created so that a new selection or compensation plan can be evaluated.

6.4.4.7 Segmental studies. Some research seeks a "general theory"—a broad, inclusive generalization that will explain a large area of human behavior. Most employment relations research has no such objective. Rather, it seeks to understand behavior in employment relationships by accumulating solutions to small segments of the whole. It is thus

segmental in its approach. It assumes that progress is aided by increased understanding of even the smallest portion of employment relationships. It particularly stresses the value of "additive" studies—i.e., studies that can be combined with others to build a growing body of understanding.

6.4.5 Additive projects. Additive projects are of great value in employment relations research. An individual firm's analysis of the accident experience of older employees, checked and verified against five or 50 other small studies, provides a reliable basis for generalization. Moreover, the generalizations can be verified from time to time. Progress toward understanding in employment relations depends largely on the accumulation and synthesis of numerous small, carefully designed studies. No firm or union is too small to undertake such a study. None should hesitate because its particular contribution does not promise to be revolutionary. Individual students can make highly valuable contributions by conducting additive studies.*

6.4.6 Steps in project development. The following procedure is appropriate in approaching most of the problems studied in employment relations research:

1. Statement of the problem.
2. Development of working or operational hypotheses.
3. Statement of assumptions.
4. Check of relevant literature.
5. Development of design and methodology.
6. Collection and analysis of data.
7. Outline of findings and conclusions.

These are, of course, only illustrative; each study requires modifications and variations. Some studies may result in recommendations and reports, which should, whenever possible, be written up and submitted for publication, for the benefit of the entire field.*

6.4.7 Research units and agencies. The problems of employment relationships have created wide interest, not only among employers, but among employees, unions, and the public. As a result, research is sponsored by many individuals and agencies. Many personnel, industrial relations, labor relations, and employment relations divisions in private industry include specialized research units with continuing research programs. Other departments also undertake special research projects from time to time. Most international unions now maintain research divisions, and many state and local federations and councils include specialized research agencies. Many employers' associations have continuing research programs.

In addition to employers and employees and their associations, many public and semi-public agencies undertake studies in the employment relations field.

6.4.7.1 Individual firm research. The research division of a firm's employment relations staff is expected to carry on continuing studies of hours, wages, em-

* See Edward McCrensky, "Some Trends in Human Relations Research," *Personnel Administration,* Vol. 14, No. 2, March 1951, 10-12; F. Stuart Chapin, *Experimental Designs in Sociological Research* (New York: Harper and Brothers, 1947), p. 1; Robert Hoppock and H. Allan Robinson, "Job Satisfaction Researches of 1950," *Occupations,* Vol. 29, No. 8, May 1951, 572-578; see especially the annual reports on research in progress published in *Personnel,* and the "Memorandum on University Research Programs in the Field of Labor," Social Science Research Council, 1947, 1948, 1949, and 1950; "Training and Research in Industrial Relations," *Bulletin No. 1* (1945); "Training and Research in Industrial Relations (II)," *Bulletin No. 4,* (1947); "Training and Research in Industrial Relations (III)," *Bulletin No. 7* (1948), all of the University of Minnesota Industrial Relations Center; also Dale Yoder, Herbert G. Heneman, Jr., and Earl P. Cheit, "Triple Audit of Industrial Relations," University of Minnesota Industrial Relations Center, *Bulletin No. 11,* 1951.

* See David B. Hertz, *The Theory and Practice of Industrial Research* (New York: McGraw-Hill Book Company, Inc., 1950), Chapters VIII and X; see also "Evaluating the Performance of Research Personnel," American Institute for Research, University of Pittsburgh, August 1951.

ployment, insurance and other benefits, and other working conditions. It may also undertake special projects essential to its reviewing function, and may be given special assignments upon request from the line organization. The responsibilities of a research unit have been summarized by one research director as follows:

1. Maintain contact with current developments in industrial relations methods and procedures, both within and outside the company.
2. Prepare data and collect and interpret experience in application of experiments in such matters as:
   a) Wage payment and employee incentive principles
   b) Utilization of personnel and employee productivity
   c) Evaluation of performance of employees
   d) Innovations in personnel administration methods and other developments

   Typical
3. Prepare special studies of company practices as directed.
4. Prepare proposals for trial adoption by interested local divisions or units of the company.
5. Counsel with local divisions or units of the company in carrying through experimental projects.
6. Maintain library of data pertinent to the activities of the department.
7. Assemble, analyze, and furnish opinions on current trends affecting employee relations on such matters as:
   a) Real wage vs. dollar wages
   b) Cost of living
   c) Wage and salary increase factors
   d) Current economic thinking
   e) Strike trends, Strike losses, Strike costs — National, Industry-wide, Company-wide

   Typical of matters to be treated statistically

A study of the functions of research directors in industry reveals an emphasis on construction and validation of tests, analysis of absences and quits, studies of policy and employee manuals, interviewing, and merit rating, the conduct of employee attitude surveys, development of personnel audits, and studies of periodic reviews. Figure 4.30 outlines in greater detail the job of the research director in an industrial relations staff.

6.4.7.2 Union research. Many unions conduct research on such matters as changes in wages and salaries, the impact and effect of "fringe" provisions, levels of employment, wage differentials, the way various contract clauses have worked, arbitrators' decisions, and the effectiveness of various organizing techniques. They have created research departments not unlike those maintained by industrial relations divisions in private industry. These departments may be set up by the international unions or by state and local federations and councils. Both the AFL and the CIO have such units. They include specialists—economists, statisticians, and others—who design and direct studies on important questions facing union officials.

A survey of the responsibilities of union research directors shows a tendency to emphasize studies of economic trends, comparative wage rates, the financial condition of companies and industries, legislation affecting unions, clauses in collective agreements, labor turnover and mobility, the competitive position of firms, labor productivity and labor costs, technological changes, wage differentials, job evaluation, and wage incentive plans.*

6.4.7.3 Governmental research. Federal, state, and local public agencies are also active in employment relations research. The federal government is represented by the United States Employment Service, the Civil Service Commission, the Bureau of Labor Statistics, the National Labor Relations Board, the Federal Mediation and Conciliation

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* Philip H. Kriedt and C. Harold Stone, "Industrial Relations Positions and Personnel," University of Minnesota Industrial Relations Center, *Mimeographed Release No. 1*, July 1950, 57; see also J. B. S. Hardman and Maurice Neufeld, *The House of Labor* (New York: Prentice-Hall, Inc. 1951), Chapters 18-21.

FIG. 4.30 JOB OF THE DIRECTOR OF PERSONNEL RESEARCH*

Title—Director of Personnel Research

Alternate Titles—Planning and Research Director, Director of Research and Development

Promotion to—Industrial Relations Director

Promotion from—Personnel Statistician, Personnel Director

Duties—The individual holding this position is responsible for research undertaken by the Department of Industrial Relations. He plans and assigns research projects and directs and supervises his assistants in their work; coordinates the research activities of this department with those of similar departments in other firms and agencies; exercises control over standards; prepares a periodic progress audit; performs advisory and service functions to the other departments; assists with the development of job analyses and the preparation of job specifications, and the development and standardization of selection tests. He supervises and directs research on: wages, job evaluation, collective bargaining, labor supply, labor turnover, absenteeism, accident proneness, employee attitudes, morale, qualifications for jobs, incentive plans, statistical reports, special reports, merit rating plans, employee induction procedures, and rehabilitation of returning veterans.

He conducts analyses and prepares reports on new developments and progress in methods, standards, and administrative trends in other companies; examines questionnaires and functional charts and arranges desk audits for classification problems; keeps departmental officials informed of tentative conclusions from surveys; acts as a consultant on special problems concerning manpower; continually evaluates policies in order to determine better methods of accomplishing the divisions' objectives; prepares all final survey reports and compiles statistics and reports on various personnel activities for management, Department of Labor, and other agencies.

Responsibility for Policy—Makes policy recommendations to the Industrial Relations Director based on evaluations of data obtained through research.

Initiative Required—A high degree of initiative is essential in originating and carrying out research ideas.

Responsibility for Work of Others—Supervises the statisticians, business machine operators, and clerks involved in research work.

Training—Some on-job training is necessary, but general professional training and experience are of primary importance.

Working Hours—Hours are frequently long and irregular.

Qualifications for Employment—

Sex: A man is preferred, but a woman is occasionally accepted.

Education: A minimum of four years of college training, and a Ph.D. degree in economics, psychology and statistics are desirable. Important college courses are: labor economics, psychometric and advanced statistical methods, research techniques, personnel management, industrial, personnel, and experimental psychology, industrial methods, safety engineering, labor problems and labor legislation, time and motion study, production standards, IBM machine operation, and accounting.

Experience: Several years of experience in research work and in assigning and directing the work of others are desirable.

Personal Qualities: Ability to handle factual data with accuracy, thoroughness, intellectual integrity, ability to assign and direct work of others.

Mental Ability: Equivalent to a superior college graduate.

Special Knowledge: Familiarity with a great variety of statistical techniques together with a knowledge of the most effective ways of reporting results of research work.

* From Kriedt and Bentson, "Jobs in Industrial Relations," pp. 44-45. Reprinted by permission.

Service, the National Security Resources Board, and the several military services, particularly the United States Air Force. State and local government agencies that frequently undertake research include the employment services, the conciliation and mediation services, industrial commissions, fair employment practice commissions, and other agencies whose operations bring them into the employment field.

6.4.7.4 University programs. Related academic departments in many public and private universities have also undertaken research in the employment relations field. The Social Science Research Council has created a special Labor Market Research Committee. Some 20 universities have established special industrial relations centers and institutes whose major responsibility is to conduct research.

6.4.7.5 Association research. A number of professional and trade associations have long been active in employment relations research. Among the most active are:

American Management Association, 330 West 42nd Street, New York. Publishes *Personnel, Management Review,* and several series in which discussions of personnel problems frequently appear.

American Society for Personnel Administration, 2917-34 East 79th Street, Cleveland 4, Ohio. Publishes the *A.S.P.A. Personnel News Bulletin.*

Committee for Economic Development, 444 Madison Avenue, New York 22, New York. Publishes reports on current economic problems.

Industrial Relations Counselors, Inc., 1270 Sixth Avenue, New York. Maintains consulting service and publishes *Library Bulletin* (bibliography), weekly summary of developments, and reports of studies.

National Association of Manufacturers, 14 West 49th Street, New York. Maintains an industrial relations department and publishes pamphlets revealing results of inquiries among its members at irregular intervals.

National Industrial Conference Board, 247 Park Avenue, New York. Publishes the *Conference Board Bulletin* (monthly), the *Conference Board Service Letter,* formerly the *Service Letter on Industrial Relations* (monthly), *Road Maps of Industry* (twice monthly), the *Management Record* (monthly), the *Economic Almanac* (occasional), the *Management Almanac* (occasional), and numerous reports in book form.

National Safety Council, 20 North Wacker Drive, Chicago. In addition to numerous bulletins, it publishes the *National Safety News* (monthly), *Public Safety* (monthly), *Safety Education* (monthly), and the *Safe Worker* (monthly), and *Accident Facts* (annually).

Psychological Corporation, Inc., 522 Fifth Avenue, New York. Provides psychological advice for industry, conducts examinations, distributes testing material, and provides vocational guidance.

Society for Personnel Administration, Box 226, Washington, D. C. Publishes *Personnel Administration* (bi-monthly).

Society for Advancement of Management, Inc., 74 Fifth Avenue, New York. Publishes *Advanced Management* (quarterly).

Twentieth Century Fund, 330 West 42nd Street, New York. Publishes books, study outlines, and pamphlets.

6.4.8 Publications. Results and findings in research are of maximum value only when they are communicated throughout the field. Consequently, reports are presented at professional meetings and conferences and through publication of research results. For those who want to follow these reports or to look up studies in any special area, the following list of publications may be helpful:

1. *Advanced Management,* Society for Advancement of management, Inc., 74 Fifth Avenue, New York 16, New York. Combined with *Modern Management.* Successor to *The Society for the Advancement of Management Journal,* the *Bulletin of the Taylor Society,* and the *Society of Industrial Engineers Quarterly.* Monthly since 1937. Numerous discussions and reports on personnel policies and practices.
2. *Conference Board Management Record,* National Industrial Conference Board, 247 Park Avenue, New York. Monthly since January, 1939. Special reports on Conference Board Studies, book reviews, labor and management statistics.

2a. *Executive's Labor Letter,* National Foremen's Institute, 100 Garfield Avenue, New London, Connecticut. Bimonthly. Background material and current developments in labor relations.
3. *Human Relations,* Tavistock Institute of Human Relations, London, and Research Center for Group Dynamics, Massachusetts Institute of Technology, Cambridge, Mass. Quarterly since 1946. "Journal of studies toward the integration of the social sciences." Frequent references to industrial relations problems.
4. *Industrial and Labor Relations Review,* Cornell University, Ithaca, New York. Quarterly since Fall, 1947. Reports of research conferences, and technical articles.
5. *Industrial Medicine,* Industrial Medicine Publishing Company, 605 North Michigan Avenue, Chicago, Illinois. Monthly since 1941. Emphasis on health programs in industry, with reports on health hazards, occupational diseases, handicapped workers, medical services, and related subjects.
6. *Industrial Nursing,* Industrial Medicine Publishing Company, 605 North Michigan Avenue, Chicago, Illinois. Monthly since 1941. Contents indicated by title, but articles of general interest to industrial relations workers appear frequently.
7. *Industrial Psychology and Personnel Practice,* Department of Labour and National Service, Melbourne, Australia. Quarterly since 1945. Reports of research in Australia and abroad, book reviews, and abstracts of articles from numerous other foreign and domestic publications.
8. *Industrial Training Abstracts,* Department of Personnel Methods, Wayne University, Detroit, Michigan. Four issues annually, since 1947. Abstracts articles dealing with apprentice, foreman and supervisory, safety, sales, and related types of training in industry.
9. *Industrial Welfare and Personnel Management,* Industrial Welfare Society, Inc., 14 Hobart Place, Westminster, S.W. 1. Formerly *Boy's Welfare Journal, Journal of Industrial Welfare,* and *Industrial Welfare.* Monthly since 1918. Contents indicated by title.
10. *International Labour Review,* International Labour Office, Geneva. Monthly since 1919. Special articles deal with all aspects of labor relations. Statistical section maintains continuing series on wages, hours, and other conditions of employment.
11. *John Herling's Labor Letter,* John Herling's Labor Letter, Inc. 1003 K Street N.W., Washington 1, D. C. Formerly *Charles Wright's Labor Letter.* Published weekly. Discusses current labor topics.
12. *Journal of Applied Psychology,* American Psychological Association, 1515 Massachusetts Avenue, N.W., Washington, D. C. Bi-monthly since 1917. All phases of applied psychology.
13. *Labour Gazette,* Department of Labour of Canada, Ottawa. Monthly. A "review of the labour-industrial situation throughout Canada." Includes articles, statistics, and reviews.
14. *Labor Market,* United States Employment Service, Department of Labor. Monthly. Reports on labor market conditions and prospects, also on problems faced by the employment service in various areas.
15. *Labor Law Journal,* Commerce Clearing House, Inc., 214 North Michigan Avenue, Chicago 1, Illinois. Monthly. A continuing survey of important legislative, administrative and judicial developments and articles on subjects pertaining to legal problems in the labor field.
16. *Labor Report,* Prentice-Hall, Inc., 70 Fifth Avenue, New York 11, N. Y. Weekly. Articles on all phases of the labor field, including legal problems involving wages, hours, union representation, and working conditions, as well as such matters as personnel administration, contract negotiation, and the like.
17. *Management Review,* American Management Association, 330 West 42nd Street, New York. Monthly since May, 1912. Frequent articles on industrial relations.
18. *Monthly Labor Review,* Bureau of Labor Statistics, U. S. Department of Labor, Washington, D. C. Since July, 1915. Summaries of studies in industrial relations. Statistical section includes continuing series on industrial disputes, employment, pay rolls, and cost of living.
19. *Occupational Psychology,* British National Institute of Industrial Psychology, 142 St. Vincent Street, Glasgow, Scotland. Quarterly since 1922 (formerly

The Human Factor and the *Journal of the National Institute of Industrial Psychology*). Reporting of cooperative studies with industry.

20. *Occupations,* National Vocational Guidance Association, 82 Beaver Street, New York. Monthly since 1922. Special interest is occupational counseling and guidance.

21. *Personnel,* American Management Association, 330 West 42nd Street, New York. Quarterly since January, 1919 (suspended, November, 1921), bimonthly since April, 1927. Entire field of industrial relations.

22. *Personnel Administration,* Society for Personnel Administration, Washington, D. C. Monthly except July and August since 1939. Articles on all phases of personnel administration, with a distinct governmental flavor.

23. *Personnel Journal,* Personnel Journal, Inc., Swarthmore, Pennsylvania. Formerly *Journal of Personnel* and formerly published by the Personnel Research Federation. Monthly, except July and August, since May, 1922. Broad coverage over the entire field.

24. *Psychological Abstracts,* American Psychological Association, 1515 Massachusetts Avenue, Washington, D. C. Monthly since 1927. Includes one section of abstracts of the literature of personnel psychology.

25. *Public Personnel Review,* Civil Service Assembly of the United States and Canada, 1313 East 60th Street, Chicago, Illinois. Quarterly since 1940. Major emphasis on personnel problems in government service.

26. *Supervision,* Supervision Publishing Company, Inc., 404 North Wesley Avenue, Mount Harris, Illinois. Combines the *Foreman.* Monthly since 1939. Numerous discussions of industrial relations with special emphasis on problems of foremen and supervisors.

6.4.8.1 Labor services. With the growing participation of government in employment relations and the creation and expansion of regulatory agencies, administrative rulings and interpretations of law have assumed much greater importance in the daily operation and administration of employee relations programs. Several specialized services have appeared, designed to provide up-to-date information on legislative changes and administrative rulings. Some of them, such as the services published by Prentice-Hall, Inc., also report on arbitration awards, which have assumed increasing importance as terminal arbitration clauses have become general. Among the most inclusive of these services are the following, listed with the agencies that provide them:

1. The Bureau of National Affairs, Inc., 1231 Twenty-fourth Street, N.W., Washington, D. C. Services include: *Collective Bargaining Negotiations and Contracts, Labor Relations Reporter, Manual of Labor Supervision.*
2. Commerce Clearing House, Inc., 214 N. Michigan Avenue, Chicago 1, Illinois. Services include: *Labor Cases, Labor Law Guide,* and others.
3. Government Statistics Bureau, 631 Pennsylvania Avenue, Washington, D. C. *The Handbook of Basic Economic Statistics* and *Monthly Supplements.*
4. National Foremen's Institute, Inc., Deep River, Connecticut. *Executive's Labor Letter* (bi-weekly) and (at ten-day intervals) *Employee Relations and Collective Bargaining;* also numerous special reports.
5. Prentice-Hall, Inc., 70 Fifth Avenue, New York 11, New York. Services include: *Complete Labor Equipment, Labor Relations Service, Wage and Hour Service, Personnel Practices—Manpower Service, Union Contracts and Collective Bargaining Service, Employee Relations and Arbitration Service, Pension and Profit-Sharing Service, Social Security Taxes Service, The Labor Report, Labor Guide, American Labor Cases, Payroll Service.*
6. Research Institute of America, 292 Madison Avenue, New York. Publishes the *Labor Coordinator.*

6.4.8.2 Reading habits of staff. A study of the publications read by employment relations staff personnel and of the services they use and the associations in which they participate is summarized in Figures 4.31 and 4.32.

FIG. 4.31 PUBLICATIONS READ BY EMPLOYMENT RELATIONS STAFF MEMBERS, 1950*

Publication	Numbers of manpower managers reporting readership: Employer representatives	Union representatives
Advanced Management	42	5
American Business	125	10
American Federationist	28	59
American Labor Education Service News Letter	8	29
Arbitration Journal	26	24
Benefit Series (Federal Security Agency)	7	8
Business Week	163	59
Chester Wright's Labor Letter	12	18
CIO News	61	54
DM Digest	12	3
Economic Indicators	5	20
Economic Notes and Labor Facts	4	11
Economic Outlook	48	42
Educational and Psychological Measurement	8	0
Employment Service Review	37	15
Executive's Labor Letter (National Foremen's Institute)	101	10
Facts for Workers	4	19
Industrial and Labor Relations Review	48	26
Industrial Hygiene Newsletter	22	6
Industrial Medicine	18	1
Industrial Nursing	32	0
Industrial Training Abstracts	4	0
International Labour Review	5	24
Journal of Applied Psychology	33	2
Journal of Industrial Training	5	1
Labor	15	40
Labor and Nation	8	33
Labor Information Bulletin	32	41
Labor's Monthly Survey	44	47
The Labor Market	19	17
Labour Gazette	2	7
Management News (American Management Association)	65	4
Management Record (National Industrial Conference Board)	118	14
Management Review (American Management Association)	84	3
Modern Industry	99	5
Modern Management	53	5
Monthly Labor Review	70	42
National Safety News	91	6
Occupations	19	1
Personnel	132	2
Personnel Administration	26	2
Personnel Series (American Management Association)	126	3
Previews (National Industrial Conference Board)	95	8
Public Opinion Quarterly	14	6
Public Personnel Review	2	2
Safety Bulletin	22	10
Social Security Bulletin	19	39
Supervision	104	1
Survey of Current Business	15	23
Workers Education Bureau News Letter	1	32

* From Yoder and Nelson, "Manpower Managers—Their Habits, Haunts, and Customs," 416.

FIG. 4.32 ASSOCIATION MEMBERSHIPS OF EMPLOYMENT RELATIONS STAFF MEMBERS, 1950*

Association	*Numbers of manpower managers reporting membership*	
	Employer representatives	*Union representatives*
American Economic Association	1	11
American Labor Education Service	1	26
American Management Association	133	4
American Psychologicaal Association	4	2
American Society for Personnel Administration	19	2
American Society of Safety Engineers	24	2
American Society of Training Directors	19	1
American Statistical Association	2	8
Industrial Relations Research Association	18	22
Labor Bureau, Inc.	0	6
Labor Research Association	1	9
National Industrial Conference Board	58	8
National Office Management Association	28	1
National Safety Council	75	17
National Vocational Guidance Association	24	4
Society for the Advancement of Management	63	3
Workers Education Bureau of America	1	26

* From Yoder and Nelson, "Manpower Managers—Their Habits, Haunts, and Customs," 415.

Marvin E. Mundel, Associate Director of the Management Center, Marquette University, is well known internationally for his work in motion and time study and other industrial engineering fields. He is the author of two books and more than 60 articles on these subjects. His writings have appeared in such magazines as *Factory*, *Iron Age*, *Mill and Factory*, *Machine Design*, *Advanced Management*, and *Modern Management*. Many of his books and articles have been reprinted in England, Italy, Sweden, Germany, and France. In 1953 he was awarded the Gilbreth Medal by the Society for Advancement of Management for his contributions to the field of scientific management.

Dr. Mundel earned his Bachelor of Science degree in Mechanical Engineering at New York University and his M.S. and Ph.D. degrees in Industrial Engineering at the University of Iowa. He taught at the University of Iowa, Bradley University, University of Birmingham (England) and Purdue University, where he was Professor and Chairman of Industrial Engineering. He was employed as an industrial engineer by the Duroyd Die and Gasket Company and the Tung-Sol Lamp Works. Many large industrial concerns, as well as the United States Army and Navy, have employed him as a consultant.

In addition to considerable basic and applied research, Dr. Mundel was one of the initiators of the nation-wide programs of Farm Work Simplification and Work Simplification for home economists that were started in the early 1940's. He was also the first Director of the Army Ordnance Management Engineering Training Program at the Rock Island Arsenal. This program provides management engineering training for personnel from all Ordnance establishments in the United States.

He is a member of American Society of Mechanical Engineers, Society for Advancement of Management, and American Society of Engineering Education.

SECTION 5

Motion and Time Study*

Marvin E. Mundel

1. DEFINITION OF MOTION AND TIME STUDY

1.1 GENERAL DEFINITION

Motion and time study deals with (1) the scientific determination of preferable work methods, (2) the appraisal, in terms of time, of the value of work involving human activity, and (3) the development of material required to make practical use of these data.

1.2 INTERRELATIONSHIP OF MOTION AND TIME STUDY

It is difficult to separate these three phases, since a specified method is one of the conditions of time measurement, and time measurements often provide a basis for comparing alternative methods. In addition, method determination and time appraisal complement the utility of each other in application. The combined term—motion and time study—is used to denote all three phases of activity: method determination, time appraisal, and the development of material for the application of these data.

1.3 UNIVERSAL APPLICABILITY

In any activity or occupation, motion and time study can help find a preferred way of doing the work and

* The material in this section is, in great part, adapted from M. E. Mundel, ***Motion and Time Study: Principles and Practice***, 2nd ed. (N. Y.: Prentice-Hall, Inc., 1955).

can provide measurements for controlling the activity. The motion and time study approach fits all human activities, including heavy or light factory work, storage or warehouse operation, farm work, housework, surgery, cafeteria work, department store or hotel work, and battle activities. What is accomplished by the work may vary from job to job, and the field of knowledge covering the raw material, product design, process, tools, equipment, and workplace may shift, but the human effort is always composed of the same basic acts. Consequently, the procedures for selecting a preferable method are essentially the same, and information relating to the economical use of human effort is universally applicable. Further, if managerial controls are to be effective, time study (or work measurement, as it is sometimes called) is always a basic requirement.

Motion and time study enables the various divisions of an organization to cooperate in selecting and planning the proper integration of materials, design of product or work achieved, process, tools, workplaces and equipment, and hand and body motions. Motion and time study techniques are aids for systematically performing many industrial engineering activities.

2. SHORT HISTORY

2.1 EARLY BEGINNINGS

The prototype of modern time study appears to be the work begun in 1881 by Frederick W. Taylor, Chief Engineer of the Midvale Steel Co. The first widespread paper relating to this activity was entitled "Shop Management," Paper No. 1003, *American Society of Mechanical Engineers*, 1903, authored by Taylor. The prototype of modern motion study appears to be the work done during the late 1800's and early 1900's by Frank B. Gilbreth resulting in a chapter on "Motion Study" in *Bricklaying System*, F. B. Gilbreth, Myron C. Clark Publishing Company, Chicago, 1909. This chapter formed the basis of *Motion Study*, F. B. Gilbreth, D. Van Nostrand Co., N. Y., 1911. These early works were closely associated with an integrated approach to what was called, "scientific management." Other than a few later highlights, space does not permit detailing the history beyond this point. Yost* has pointed out that the periodicals listed in the *Readers Guide* included 150 articles on the subject between 1911 and 1914, together with an even greater number in the technical and trade journals and newspapers for those years. During this later period, the full compatibility of the two approaches began to emerge.

2.2 FORMALIZATION OF THE FIELD

Gilbreth followed his early work with *Applied Motion Study*, Sturgis and Walton Co., N. Y., 1917, *Fatigue Study*, The Macmillan Company, N. Y., 1919, and *Motion Study for the Handicapped*, George Routledge and Sons, London, 1920. These later works were done in collaboration with his wife and co-worker, Lillian M. Gilbreth. Also, to the main stream of published material was added the work of Jules Amar in France (available as *The Human Motor*, George Routledge, London, 1920), the work of Atzler in Germany, of Cathcart and Benedict published by the *Carnegie Institution of Washington D. C.* and the work of the *Industrial Fatigue Research Board* and the *Industrial Health Research Board* of Great Britain, beginning about the time of World War I. There were also numerous other contributors in many countries in the fields of industrial engineering, industrial psychology, and physiology. It is almost impossible to summarize this period without slighting (unintentionally) many who contributed greatly to this growing field. Considerable assistance was given to its growth by the number of articles published in

* Edna Yost, *Frank and Lillian Gilbreth* (New Brunswick, N. J.: Rutgers University Press, 1949), p. 188.

the McGraw-Hill magazine *Factory*, under the editorship of L. C. Morrow.

2.3 EARLY TEXTBOOKS

Academic work in motion and time study was somewhat limited by the unavailability of suitable texts until the publication of *Time and Motion Study*, by S. M. Lowry, H. B. Maynard, and G. J. Stegemerten, McGraw-Hill, N. Y., 1927; *Common Sense Applied to Motion and Time Study*, A. H. Mogensen, McGraw-Hill, N. Y., 1932; and *Motion and Time Study*, R. M. Barnes, Wiley, 1937, this last volume being an expansion of an earlier lithoprinted book by the same author. Although these early texts have largely been displaced by later editions or later works by other authors, they stand as historic landmarks in the subject.

2.4 LATER DEVELOPMENTS

By the 1940's the number of texts and related books began to grow to an imposing list and work in the area was firmly established on a scientific basis, on an international scale, and as a regular part of the normal industrial routine of the civilized world.

3. MOTION STUDY

3.1 DETAILED DEFINITION

Motion study is a scientific, analytical procedure for determining a preferable work method, considering:

a. The raw materials.
b. The design of the product.
c. The process or order of work.
d. The tools, workplace, and equipment for each individual step in the process.
e. The hand and body motions used in each step.

The criterion of preference is usually economy of money, but other criteria such as ease or economy of human effort, economy of work time, in-process time, material, skill, space, machine time, tools, etc., frequently may take precedence.

3.2 USES

The basic use of motion study is implicit in the definition given in Art. 3.1. However, motion study is also applicable to:

a. Improving a work method by locating deficiencies in any of the five individual factors involved (see Art. 3.1) or in their interrelationships.
b. Improving a work method by assisting in adjusting the pattern of interrelationships or any of the individual characteristics of the five factors involved to meet: (1) new economic conditions, (2) changes in criterion of preference, (3) new materials or equipment.
c. Designing a work method through logical analysis and synthesis.
d. Providing a schematic framework for organizing knowledge about the interrelationships and individual characteristics of the five factors involved.

3.3 STEPS IN THE APPLICATION

The scientific method of solving problems involving the determination of a preferred way of doing a job, a preferred method of production, or a preferred method of doing new work requires the application of a logical procedure consisting of the following seven steps:

A. *Aim*—Determination of objective in terms of area of job to be changed, and establishment of criteria for evaluating the preferability or success of solutions. Innovations may be introduced in any one of the five areas that affect the performance of the job. These areas are:

1. *Hand and body motions*

The particular motions, their se-

quence, and their nature may be changed to ease or improve the task.

2. *Work station (tools, workplace layout, or equipment)*
The design of any single work station or the equipment used for any part of the task may be modified.
3. *Process or work sequence*
The order or condition in which the various work stations receive the product may require change or the number of work stations may be modified.
4. *Product design, form of goods sold, or material or service produced*
The final form of the product, as it leaves the organization, may require slight modification to facilitate the attainment of the objectives of improvement.
5. *Incoming supplies or raw material*
The materials brought into the organization may require change in form, condition, or specification in order to allow the desired improvements to be made.

A change in any of these factors with numbers above 1 usually must be accompanied by changes in the areas with lower numbers in order to accommodate the change. Also, a change beginning in Area 3, 4, or 5 is usually evaluated with the assistance of an analysis of what happens to the product; a change beginning in Area 1 or 2 with an analysis of work performed by a man. Reference to these areas (usually referred to as "classes") may help clarify instructions given to the analysts.

B. *Analysis*—Analysis of the work method into subdivisions or steps possessing known characteristics, or concerning whose performance information is already available which are pertinent to the problem and are relatively unique or singular in nature, and graphic or tabular presentation of the actual or contemplated sequence of these steps. These analyses may be divided into two main groups: those for analyzing activity of the product and those for analyzing activity of people.
C. *Criticism*—Checking the analysis against basic data, check lists of desirable arrangements of the steps into a preferable work pattern, and information concerning desirable ways of performing each of the steps.
D. *Innovation* (synthesis) — Formulating a new procedure for performing the work.
E. *Test*—Testing, by means of the data used in Step C, the desirability of the method formulated in Step D, in respect to the objectives set up in Step A.
F. *Trial*—Making a sample application of the method tested in Step E to ascertain whether all variables have been taken into account.
G. *Application* — Standardizing, installing, evaluating, and maintaining the improved work method.

3.4 LISTS OF TECHNIQUES

Motion-study techniques may be listed under the steps of the logical procedure which they implement. Techniques for the study of current activity are usually made by means of direct observation or by means of micromotion or memomotion study. (See Art. 3.5 for definitions.) In studying a contemplated activity, they may be used to detail the concept. In the following lists those marked by an * indicate analyses which may be made by micromotion or memomotion study. In some of these cases, analysis by direct observation is difficult, if not impossible.

3.4.1 For determining *Aim.*

a. Possibility guide or list.
b. Activity chart.
c. Machine load chart.
d. Functional form analysis chart.

3.4.2 For performing *Analysis.* These techniques are divided into two major groups, product and man, as explained in Art. 3.3B.

3.4.2.1 For product analysis.

a. Process chart—product analysis.

b. Flow diagram.

c. Procedure analysis chart (in some cases this also shows personnel actions).

3.4.2.2 For man analysis.

a.* Process chart—man analysis.

b.* Man flow diagram.

c. Workplace layout.

d.* Operation chart.

e.* Multiple-activity analysis.

1. Man and machine (or multimachine) operation chart.
2. Man and machine (or multimachine) operation time chart.
3. Man and machine (or multimachine) process chart.
4. Man and machine (or multimachine) process time chart.
5. Multi-man operation or process chart.
6. Multi-man operation time or process time chart.
7. Multi-man charts similar to 1, 2, 3, or 4 above.

f.* Micromotion study

1. Simo (simultaneous motion cycle) chart.
2. Memomotion charts (time sequence, flow or tabular).

g. Cyclegraphic or chronocyclegraphic records

3.4.3 For *Criticism*. Available check lists and basic data are arranged in suitable form for use with each of the techniques given under Arts. 3.4.1 and 3.4.2.

3.4.4 For *Innovation*. The techniques used to present the innovation are usually similar to those used to make the *Analysis* (see Art. 3.4.2).

3.4.5 For *Test*. A proposed solution may be tested against the basic data referred to in Art. 3.4.3 and against the criteria set up in determining the *Aim* (Art. 3.3). Summaries of what will be achieved are often needed in evaluating the utility of a proposed solution. The following forms are useful:

a. Methods proposal summary.

b. Procedure proposal summary.

3.4.6 For *Trial*. Formal permission to conduct a trial should be obtained through routine channels and procedures.

3.4.7 For *Application*. This step usually requires the preparation of what is variously called a WSP (Written Standard Practice), SOP (Standard Operating Procedure), a layout (see Section 8 on Plant Layout), a tool, the design of a machine design or workplace (see any standard text on drafting practice), or an operator instruction sheet or procedure instruction (Section 6).

3.5 DEFINITIONS OF TECHNIQUES

The techniques listed under Art. 3.4 are defined below. Again, most of them are applicable either to an existing job or process or to a projected job or process.

3.5.1 For *Aim*. These techniques are designed to help the analyst select the most feasible type of change. They help him select the appropriate analysis procedure for performing the next step of the motion study. This relationship is given in Table 5.1.

3.5.1.1 Possibility guide. This is a systematic list of all possible changes suggested by the person familiar with the activity or product under scrutiny. It also shows the consequences of each suggestion.

3.5.1.2 Activity chart. This is a chronological record of the various activities of an individual performing a variety of tasks. It includes a summary of the nature of each activity, the work-units produced, and the time spent at each activity. Several activity charts may be combined into a work distribution chart, described in Art. 3.5.1.3.

3.5.1.3 Work distribution chart. "A tabulation of the various tasks performed by the individuals in an organization classified in accordance with the major activities of that organization. Time spent by each individual on each task is indicated, so that a completed chart will show the total manhours spent on each activity." *

* Techniques of Work Simplification," Department of Army, *Pamphlet No. 20-300,* June 1951, 3.

TABLE 5.1 SELECTING THE ANALYSIS TECHNIQUE*

Class of change sought	Physical characteristics of job	Technique recommended	Equipment required	Notes
5, 4, 3	Several work stations in process.	Process chart-product analysis.	Paper and pencil.	Rapid analysis.
5, 4, 3	Flow of paperwork or control form.	Procedure analysis chart.		Rapid analysis of complex situations.
2 or 1	Person moves from place to place while doing work.	Process chart-man analysis.	Paper and pencil. Watch is sometimes used but is not necessary.	Rapid analysis.
2 or 1	Person does job at one place.	Operation chart.	Paper and pencil. Watch is sometimes used but is not necessary.	Rapid analysis and widely applicable.
2 or 1	Man operates one or more machines. Machine time is an important factor.	Man and machine charts.	Paper and pencil. Watch is desirable. Film may be used.	Rapid analysis.
2 or 1	Several men work coordinately, as a crew with or without machine or machines.			
	A—Simple task.	A—Multi-man or multi-man and machine chart.	A—Paper and pencil. Watch is desirable.	A—Difficult analysis at times.
	B—Complex task.	B—Memomotion chart.	B—Micromotion equipment.	B—Very easy to analyze.
2, 1	Long-run short cycle or detailed training material is required.	Simo chart.	Micromotion equipment.	Analysis takes some time but is less costly for detailed analysis and where much methods work is done.

* Adapted from Mundel, *Motion and Time Study: Principles and Practice*, p. 46.

3.5.1.4 Machine load chart. This is similar to an activity chart (Art. 3.5.1.2) but records the activities of a machine rather than of a person.

3.5.1.5 Functional form analysis chart. This is a tabular presentation of the activities of an organization and the forms used at each step in performing each activity. It indicates areas in which forms overlap, are inadequate, or are too numerous.

3.5.2 For *Analysis*. These techniques are described categorically in Art. 3.3B. Essentially, they provide a formal, graphic means of breaking a large problem down into smaller problems. They enable the analyst to develop or apply basic information and to synthesize satisfactory solutions.

3.5.2.1 For product analysis. These techniques are, for the most part, graphic.

Process chart—product analysis. This is a graphic presentation of the separable

steps involved in performing the work required to modify a product from one stage of completion to another.

Flow diagram. This consists of a sketch of the part of the plant concerned in the study of a product with a line tracing the path followed by the product. In some cases, the symbols from the process chart are shown at the places they occur.

Procedure analysis chart. This is a graphic presentation of the separable steps of activities with forms or other paper work, showing the interrelationships of the various papers, forms, or copies involved and can be used also to indicate the work of related individuals and/or offices and/or on products. Its primary use is to analyze paper-work routines.

3.5.2.2 For man analysis. These techniques also are primarily graphic.

Process chart—man analysis. This is a graphic presentation of the separable steps a person performs when doing a task that requires him to move from place to place in the course of his work, treating the person as a single unit.

Man flow diagram. This is a sketch of the part of a plant connected with a man's work on which a line has been drawn indicating the path the operator travels in performing this work.

Workplace layout. This is a dimensioned sketch (usually showing both plan and profile views) of the place at which a man works. It helps the analyst to understand the body and eye motions required to perform the task. The path of motions may be added, as in a man flow diagram.

Operation chart. This is a graphic presentation of the separable steps of a person's body members when he is performing a job that takes place essentially at one location and indicates the relative simultaneity of the movements of the various body members being considered. (An operation chart is an analysis of the work performed by a worker on any one operation on a process chart, either man, product, or combined analysis. It is a description of what the operator does.)

Multiple activity. These techniques are used to analyze situations in which a man works with one or more machines and in which the work of the machine is a controlling factor, and situations in which a group of men work coordinately with or without machines. To be useful, the analysis must show not only the sequence of steps, of the two or more items charted, but also the relative simultaneity of steps.

The man and machine operation chart is used to analyze the work of one operator and one machine in one location. It is similar to an operation chart, except that a third column is added for the machine. In this column, the activity of the machine is indicated by one of two symbols: the symbol for suboperation when the machine is working, and the symbol for delay when it is idle (Table 5.5). The machine is thus charted as if it were an additional body member with limited functions. If more than one machine are involved, an additional column is added for each machine.

The man and machine operation time chart is similar to a man and machine operation chart except that in place of a column of symbols, a plain vertical column and shadings of various types are used to indicate the nature of the activity, the length of each shading indicating the amount of time spent at that activity. The activities of the machine or machines are charted in a similar manner. The relative simultaneity of activity is thus indicated much more accurately.

The man and machine process chart is similar to a man and machine operation chart except that the person's body members are not charted separately. The person is treated as a single unit, as in a process chart—man analysis.

The man and machine process time chart is like a man and machine operation time chart except that the man's activities are charted as a single unit.

Multi-man operation or process chart is a graphic presentation of the separable steps of the work of a crew and indicates the relationship between the work of each member when the work involves co-

ordination of the crew. In the operation chart version, each pertinent body member of each man is charted separately. In the process chart version, each man is treated as a single unit.

Multi-man operation or process time chart differs from a multi-man operation or process chart only in that a shaded column instead of a column of symbols is used to represent each item being charted. Since the length of each shading is proportional to the amount of time spent on each step, the simultaneity of action is shown with high accuracy.

A multi-man and multi-machine chart may be made by adding a column for each machine to the two preceding types of charts.

*Micromotion study** refers to the analysis of a man work method by using a motion-picture camera with a timing device in the field of view. A constant-speed drive incorporated in the camera may serve as the timing device. Micromotion study involves three steps: filming, analysis of the film, and graphic presentation. Although the usual speed is 16 frames per second, or 1,000 frames per minute, other speeds may be more convenient. For example, speeds of 50, 60 or 100 frames per minute are exceedingly useful in studying complex and varied tasks, long-cycle or crew activities, and long-period activities. Such speeds reduce the amount of film used, and consequently the amount of film that has to be analyzed, by as much as 95 per cent. Study conducted at these slower film speeds is frequently referred to as *memomotion study*.

A *simo* (*simultaneous motion cycle*) *chart* is a graphic presentation of the separable steps of each pertinent body member of the individual being charted and is normally accompanied by the *use* of a series of 17 analysis categories called therbligs† (see Art. 3.3B and Table 5.8) together with a vertical bar for each body member charted. Since the number of separately identified categories (17) is too large for convenient use of shadings, colors are used in the vertical bars on the chart; one bar for each member is charted and the length of each colored section is made proportional to the amount of time involved. Normally, one bar is provided for each hand, but additional bars may be used for fingers, head, eyes, feet, knees, and so on. Several people, working as a crew, may be charted together.

A *memomotion chart* is a graphic presentation of the separable steps of a person's activity as taken from a memomotion film. Many of the previously described types of graphic presentations may be employed or in unusual cases a special set of categories may be developed to accommodate the requirements of the problem as suggested by the basic statement of Step B of Art. 3.3. Flow diagrams may also be employed or special tabular presentations resembling those described in Art. 3.5.1.2 may be used.

*Cyclegraphic or chronocyclegraphic records** are photographic records of a body member's path of movement. A light is attached to the body member and the movement is photographed on still film. A long shutter opening equal to the time for a movement cycle is usually used, although the opening may be shorter or longer. In cyclegraphic records, a continuous light source is used. In chronocyclegraphic records, the light is caused to flash with a nonsymmetrical peak of brilliance† so that speed and direction may be measured later. The same result may be obtained by rotating a photographic wedge‡ in front of the lens in lieu of a flashing light. Other arrangements employ stereoptical photography or two cameras at right angles to each other. A similar record may be obtained by plotting the path of a definite point

* Originated by Frank and Lillian Gilbreth.

† After Gilbreth (spelled backwards), who developed these classifications.

* Developed by Frank B. and Lillian Gilbreth.

† Developed by the Gilbreths.

‡ Developed by Professors Connolly and Wilshire, College of Aeronautics, Cranfield, England.

on a person's hand or body from successive frames of motion pictures. All these photographic techniques are exceedingly useful in studying skills.

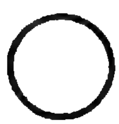
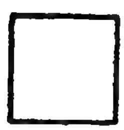
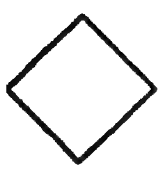
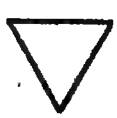
3.5.3 For *Criticism*. Check lists present desirable and undesirable features and facts common or pertinent to work of a given scope or nature. The lists are arranged in a fashion that facilitates comparison with an actual or contemplated job or process. Such a comparison helps the analyst to locate undesirable features and to insure conformance with desirable features. Basic data concerning human dimensions, capacities, and limitations should also be referred to.

3.5.4 For *Test*. Actual forms commonly used for summarizing are given in Art. 6 of this section. They are usually tabular presentations which include an organizational routing of the information and a listing of the criteria of success. They also contain pertinent facts relating to the important aspects of the proposal under consideration as well as an identification of the source of estimated data. They usually also summarize the proposal (see Art. 3.4.5).

3.6 SYMBOLS

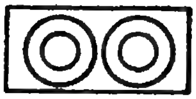
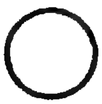
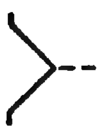
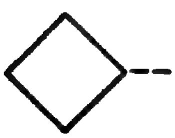
To make it easier to prepare and interpret data, almost all the graphic techniques employed in motion study use symbols to represent the various separable steps identified. These symbols, and the categories they represent, have evolved over a considerable period of time. They are designed to divide the activity under consideration into a minimum number of groups while still obtaining the benefit of division into unique categories for which basic facts may be developed. Symbols, together with the scientific method, form the basis of motion study. The same symbols are used in systems analysis.

TABLE 5.2 SYMBOLS FOR PROCESS CHART—PRODUCT ANALYSIS*

Symbol	Name	Used to represent
	Operation	Something done to the product at essentially one location.
	Quantity Inspection	A special form of operation involving the verification of the quantity of a product present against some record of the quantity that is supposed to be there.
	Quality Inspection	A special form of operation involving the verification of some attribute or quality of a product against a standard.
	Movement	A change in the location of a product which does not change it in any other way.
	Temporary Storage	The storage of a product under conditions such that it may be moved or withdrawn from storage without a requisition.
	Controlled Storage	Storage of a product under controls such that a requisition or receipting is needed to withdraw it.

* From Mundel, *Motion and Time Study: Principles and Practice*, p. 51.

TABLE 5.3 SYMBOLS FOR PROCEDURE ANALYSIS CHART*

Symbol	Name	Used to represent
	Origin of Form	Form first being made out.
	Origin of Form	Form first being made out in duplicate.
	Origin of Form	Form first being made out in triplicate, etc.
	Operation	Work being done on form; computations or additional information added, etc.
	Movement	A change in location of form, not changing it.
	Delay	Forms waiting to be worked on, such as in desk basket.
	File	Forms in a file.
	Information Take-off	Information being taken off form for entry onto another or for use by someone. Point of line indicates symbol on other parallel chart where information is going. (Use – – – – broken line to indicate destination if destination appears on chart and line is aid to clarity.)
	Disposal	Form or copy destroyed.
	Inspection	Correctness of information on form checked by comparison with other source of information. (Use – – – – broken line drawn to other source if other source appears on chart and line is aid to clarity.)
	Item Change	Change in item charted.
	Gap	Activities not pertinent to study and hence not charted in detail.

* From Mundel, *Motion and Time Study: Principles and Practice*, p. 133.

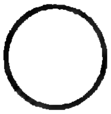
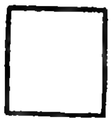
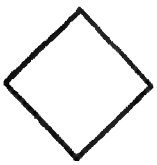
3.6.1 For product analysis techniques. These symbols relate to identifiable steps of work done on a product or item.

Process chart—product analysis: Table 5.2.

Procedure analysis: Table 5.3.

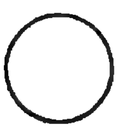
3.6.2 For man analysis techniques. These symbols relate to identifiable steps of work performed by a man and also to identifiable steps in the work

TABLE **5.4** SYMBOLS FOR PROCESS CHART—MAN ANALYSIS*

Symbol	Name	Used to represent
	Operation	The doing of something at one place.
	Quantity Determination	A special form of operation involving the person determining the quantity of an item present.
	Inspection	A special form of operation involving the person comparing an attribute of a product with a standard, or verifying the quantity present.
	Movement	A change in location; moving from one place to another.
	Delay	Idleness. Waiting or moving, provided the movement was not part of the job and the time could have been spent waiting.

* From Mundel, *Motion and Time Study Principles and Practice*, p. 92.

TABLE **5.5** SYMBOLS FOR OPERATION CHART*

Symbol	Name	Used to represent
	Suboperation	Body member doing something at one place, such as taking hold, lining up, assembling, etc.
	Movement	A movement of a body member toward an object or changing the location of an object.†
	Hold	Body member maintains an object in a fixed position so that work may be done with or on it at that location.
	Delay	Body member is idle or delaying for other body member.

* From Mundel, *Motion and Time Study: Principles and Practice*, p. 148.
† On very long operations the analyst may combine some of these steps into larger steps using, "get," in place of *reach for, take hold* of, and *bring* object to work area; "aside," meaning *move object* from work area, *let go* of object, and *return*. In such a case the chart is described as being made with "a gross breakdown" and is considerably shorter than when made with the usual steps.

TABLE 5.6 SYMBOLS USED WITH MAN AND MACHINE OPERATION TIME CHART*

Symbol†	Name	With man activities is used to represent	With machine activities is used to represent
	Suboperation	Body member or operator doing something at one place.	Machine working ("on" time), machine paced.
	Suboperation	Not used.	Machine working ("on" time), operator paced.
	Movement	Body member or operator moving toward or with an object.	Not used.
	Hold	Body member maintaining an object in a fixed position.	Not used.
	Delay	Body member or operator is idle.	Machine is idle ("down" time).

* From Mundel, *Motion and Time Study Principles and Practice*, p 180.
† The amount of shading is chosen to suggest automatically the general usefulness of the step. The less shading, the probable greater undesirability of the step.

of any machines or equipment used.

Process chart—man analysis: Table 5.4.

Operation chart: Table 5.5.

For multiple-activity analysis: These symbols are given separately for each type of chart.

Man and machine operation charts: Art. 3.5.2 explains the method of adapting the symbols shown in Table 5.5.

Man and machine operation time charts: Table 5.6.

Man and machine process charts: Art. 3.5.2 indicates the method of using the symbols shown in Tables 5.4 and 5.5.

Man and machine process time charts: Table 5.7.

Multi-man operation or process charts: Tables 5.4 and 5.5.

Multi-man time charts: Tables 5.6 and 5.7.

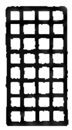
Multi-man and machine charts: Tables 5.4, 5.5, 5.6, and 5.7.

3.6.3 For micromotion study. These symbols for identifiable steps are usually associated with film analysis. But, because of detail, they are useful for detailing the concept of a contemplated job.

Simo charts. These charts usually employ therbligs as their fundamental units. Definitions of these units and the colors used to represent them on charts are given in Table 5.8.

Memomotion charts. The symbols shown in Tables 5.4, 5.5, 5.6, 5.7, and 5.8 may be used in memomotion charts. However, special sets of steps and symbols designed for special problems are often very valuable. The series given in Table 5.9 was created for an analysis of

TABLE 5.7 SYMBOLS FOR MAN AND MACHINE PROCESS TIME CHART*

Symbol	Name	With man activities is used to represent	With machine activities is used to represent
	Operation	The doing of something at one place.	Machine working ("on" time), machine paced.
	Operation	Not used.	Machine working ("on" time), operator paced.
	Quantity Determination	A special form of operation involving the person determining the quantity of an item present.	Not used.
	Inspection	A special form of operation involving the person comparing an attribute of a product with a standard, or verifying the quantity present.	Not used.
	Movement	A change in location; moving from one place to another.	Not used.
	Delay	Idleness. Waiting or moving, provided the movement was not part of the job and the time could have been spent waiting.	Machine is idle ("down" time).

* From Mundel, *Motion and Time Study: Principles and Practice*, p. 186.

air-crew activities* presented by means of a multi-man and multi-machine operation time chart. Special care should be exercised to interpret Art. 3.3B correctly so as to avoid the use of irrelevant subdivisions. Special categories may also make tabular presentations more effective. Table 5.10 gives the results of a memomotion analysis of a pharmacist's activity, together with the symbols used during the analysis. Note that Tables 5.9 and 5.10 merely suggest approaches to special problems rather than commonly used categories and symbols.

* M. E. Mundel, "Motion Study Techniques Which Could Be Brought To Bear on Desirable Size of Aircraft Crews," *Scientific Methods for Use in the Investigation of Flight Crew Requirements* (Cambridge, Mass.: The Flight Safety Foundation, 1948).

3.7 CHECK LISTS

An analyst will facilitate his activity if he will accumulate information on ways, peculiar to his industry or type of work, of improving the various type of steps concerned in each type of analysis—that is, specific ways of achieving the general suggestions implied by the check list questions contained in basic check lists (see Art. 3.3C). The following check lists are arranged in the same general order as the defi-

TABLE 5.8 THERBLIG DEFINITIONS AND SYMBOLS*

Color group and general characteristics	Therblig	Symbol	Color	Eagle pencil†	Dixon Thinex pencil	Definition
Red-blue—terminal therbligs	Grasp	G	Lake red	744	369	Begins when hand or body member touches an object. Consists of gaining control of an object. Ends when control is gained.
	Position	P	Blue	741	376	Begins when hand or body member causes part to begin to line up or locate. Consists of hand or body member causing part to line up, orient, or change position. Ends when body member has part lined up.
	Pre-position	PP	Sky blue	740½	418	Same as position except used when line up is previous to use of part or tool in another place.
	Use	U	Purple	742½	396	Begins when hand or body member actually begins to manipulate tool or control. Consists of applying tool or manipulating control. Ends when hand or body member ceases manipulating tool or control.
	Assemble	A	Heavy violet	742	377	Begins when the hand or body member causes parts to begin to go together. Consists of actual assembly of parts. Ends when hand or body member has caused parts to go together.
	Disassemble	DA	Light violet	742	422	Begins when hand or body member causes parts that were integral to begin to separate. Consists of taking objects apart. Ends when hand or body member has caused complete separation.
	Release load	RL	Carmine red	745	383	Begins when hand or body member begins to relax control of object. Consists of letting go of an object. Ends when hand or body member has lost contact with object.

TABLE 5.8 (*Continued*)

Color group and general characteristics	Therblig	Symbol	Color	Eagle pencil†	Dixon Thinex pencil	Definition
Green—gross movement therbligs	Transport empty	TE	Olive green	739½	391	Begins when hand or body member begins to move without load. Consists of reaching for something. Ends when hand or body member touches part or stops moving.
	Transport loaded	TL	Grass green	738	416	Begins when hand or body member begins to move with an object. Consists of hand or body member changing location of an object. Ends when hand or body member carrying object arrives at general destination or movement ceases.
Gray-black—hesitant movement therbligs	Search	SH	Black	747	379	Begins when hand or body member gropes or hunts for part. Consists of attempting to find an object. Ends when hand or body member has found location of object.
	Select	ST	Light gray	734½	399	Begins when hand or body member touches several objects. Consists of locating an individual object from a group. Ends when the hand or body member has located individual object.

TABLE 5.8 (*Continued*)

Color group and general characteristics	Therblig	Symbol	Color	Eagle pencil†	Dixon Thinex pencil	Definition
Yellow-orange—delay therbligs	Hold	H	Gold ochre	735	388	Begins when movement of part or object, which hand or body member has under control, ceases. Consists of holding an object in a fixed position and location. Ends with any movement.
	Unavoidable delay	UD	Yellow ochre	736	412	Begins when hand or body member is idle. Consists of a delay for other body member or machine when delay is part of method. Ends when the hand or body member begins any work.
	Avoidable delay	AD	Lemon yellow	735½	374	Begins when hand or body member deviates from standard method. Consists of some movement or idleness not part of method. Ends when hand or body member returns to standard routine.
	Rest for overcoming fatigue	R	Orange	737	372	Begins when hand or body member is idle. Consists of idleness which is part of cycle and necessary to overcome fatigue from previous work. Ends when hand or body member is able to work again.
Brown—accompanied by thinking	Plan	PN	Brown	746	378	Begins when hand or body members are idle or making random movements while worker decides on course of action. Consists of determining a course of action. Ends when course of action is determined.
	Inspect	I	Burnt ochre	745½	398	Begins when hand or body member begins to feel or view an object. Consists of determining a quality of an object. Ends when hand or body member has felt or seen an object.

* From Mundel, *Motion and Time Study: Principles and Practice*, pp. 228-231.
† The colors of some of these pencils vary somewhat from the standard colors. They have been selected to match the standard as closely as commercial pencil colors allow.

TABLE 5.9 SYMBOLS FOR USE WITH MAN AND MACHINE ANALYSIS OF AIRCRAFT FLIGHT CREW

Category	Code	Color	Dixon pencil number	Remarks
Communications				
Listen	VL	Pink	381	Striped
Voice	VV	Vermillion	371	Solid
S/P phones	VP	Red	370	Solid
Intercom	VI	Lavender	424	Solid
Radio	VR	Purple	396	Solid
Mechanical (Servo)	VS	Violet	377	Solid
Gross movements				
Walk	WL	Olive green	391	Solid
Walk and supervise	WS	May green	416	Solid
Manipulations				
Adjust or operate in a special manner	MS	Sky blue	418	Striped
Operate in a normal manner	MN	Sky blue	418	Solid
Record or write	MR	Blue	376	Solid
(If desired, this group may be expanded into the normal 17 therbligs.)				
Considerations				
Form a decision	CD	Brown	378	Solid
Compute	CC	Burnt sienna	398	Solid
Inspect	CI	Gold ochre	388	Solid
Delays				
Unavoidable idleness	DU	Yellow	374	Solid
Avoidable idleness	DA	Yellow and black	374 379	Alternate stripes
Machines or instruments				
Normally operating	ON	None		Blank
Being manipulated	OM	Black	379	Solid
(Reading on instrument . . . Show actual reading in bar, at appropriate place.)				

nitions of techniques. They are by no means exhaustive but should be used as guides to indicate the type of questioning the analyst should engage in.

3.7.1 For *Aim*. Check lists for determining Aim are given in Tables 5.11 and 5.12. In Table 5.11, which is designed to yield general ideas, the numbers of the groups of questions refer to the five classes of change described in Art. 3.3A. Table 5.12 gives possible criteria of success (see Art. 3.3A). The check list questions as well as the following general statements and questions should be considered:

The particular class of change chosen as an objective is a function of many factors.

The higher classes of change often take longer to install, affect more people, and require higher authority. Hence, in addition to the desirability or apparent feasibility of the individual suggestions, the following economic and psychological factors affecting change must be carefully considered before a final decision is made:

1. How great is the actual or expected volume, and how often does the job occur?

TABLE 5.10 SYMBOLS AND RESULTS OF ANALYSIS OF PHARMACIST'S PRESCRIPTION FILLING TIME*

Description of activity	Symbol	Rank importance	Per cent of time used
Work on labels or prescription blanks	L	1	23.3
Work wrapping	AWR	2	10.5
Work putting material into prescription containers or with containers	AM	3	10.1
Inspection of prescription blanks	IP	4	7.4
Work applying labels	AL	5	7.2
Travel to and from register	TR	6	5.4
Work counting items	AC	7	5.2
Travel to shelves or cupboards for material	TEM	8	5.0
Work with balance and accessories	AB	9	4.3
Work getting down items	AD	10	4.1
Work compounding	ACO	11	3.9
Work on drugs	ADR	12	3.3
Talking to customers	V	13	2.8
Work at cash register	CA	14	2.3
Inspection of shelves	IS	15	2.0
Inspection of drug containers or contents	IC	16	1.3
Travel to shelves or cupboards to put away	TLM	17	1.1
Work putting up items	U	18	.6
Work with liquid measures	ALI	19	.2
TOTAL			100.0

* From Mundel, *Motion and Time Study: Principles and Practice*, p. 210.

2. How long will the job exist?
3. How much time, per unit, is spent on the job?
4. How much time is available to work up the change?
5. How much equipment is already invested in the job?
6. How much analysis time will be required?
7. How much loss of production or sales will be caused by the change?
8. How much retraining will be required?
9. What saving will the change effect?
10. What is the position of the analyst in the plant organization?
11. What personalities are involved?
12. What plant policies affect the problem?
13. Is the product for plant use or for customers?
14. What do other interested groups in the organization think of the feasibility of the suggestion?

The importance of each factor will vary from case to case. The order in which they are given here does not necessarily indicate their relative importance. The analyst must weigh and evaluate them for each situation.

3.7.2 For product analysis techniques. Check lists follow for the major techniques defined in Art. 3.5.2.1.

Process chart — product analysis: Table 5.13.

Procedure analysis: Table 5.14.

3.7.3 For man analysis techniques. The following check lists relate to individual techniques and to groups of techniques.

Process chart—man analysis: Table 5.15.

Operation chart: A check list for use with operation charts is given in Table 5.16. Related basic data are given in Fig. 5.1.*

* See also *The Handbook of Human Engineering Data*, 2nd ed. (The Special Devices Center, Office of Naval Research, 1951).

TABLE 5.11 CHECK LIST FOR POSSIBILITY GUIDE*

5. Can a slightly different raw material be ordered or can the same material be ordered in a form that would be more advantageous? Can we change:
   a. Shape
   b. Size
   c. Packaging
   d. Quantity packaged together
   e. Material
   f. Amount of processing done by supplier
   g. Color
   h. Finish
   i. Any other specification
   j. The product so as to make any material or auxiliary material unnecessary
4. Can the product be made, sold, or sent out in a more advantageous form? Can we:
   a. Modify design
   b. Pack differently
   c. Change finish
   d. Change weight
   e. Change tolerances
3. a. Can we do the different jobs along the route between receiving and shipping in a different order?
   b. Is any step unnecessary?
      1. What does it accomplish?
      2. Why is it done?
      3. What would happen if it were not done?
   c. Can we combine any steps?
   d. Can we advantageously break any job into two or more separate operations?
2. a. Can any new tools or equipment or a change in the workplace make any job in the sequence easier? (This is almost always possible.)
   b. Can any tool or equipment be eliminated advantageously?
   c. Can any two tools be combined?
1. Can a new motion pattern make any job in the sequence easier? This is almost invariably true. Specific suggestions are usually more easily made after the method analyst is more familiar with the man-analysis techniques; hence, at this point, a mere list of the possible jobs that may be looked into or some rough suggestions will probably be all the student is capable of. (The analyst also tries to eliminate motions. In actual practice, as will be evident later, this part of the analysis may be done in more detailed fashion.)

* From Mundel, *Motion and Time Study: Principles and Practice*, p. 34.

Multiple activity: Check lists for use with multiple activity charts should be used in conjunction with the check lists relating to the basic charts of which they are an elaboration.

Man and machine charts: Table 5.17.

Multi-man charts: Table 5.18.

Micromotion study. Check lists are available only for commonly used breakdowns. The analyst working with unusual breakdowns will have to organize his own data.

Therbligs and simo charts: Table 5.19.

Memomotion study. If appropriate check lists are available, they should be used. In most cases, however, new check lists, related to the criteria of success being used must be created when new breakdowns are used. See Table 5.12.

TABLE 5.12 LIST OF CRITERIA OF PREFERENCE*

1. Greater economy of operation:
   a. Through less time for the job.
   b. Through less effort required by the job. (These first two are often synonymous if only manual methods are altered.)
   c. Through less scrap.
   d. Through less material in the product.
   e. Through a change in amount of indirect labor.
   f. Through the use of less expensive equipment.
   g. Through the use of fewer people.
   h. Through the use of less critical skills.
   i. Through the use of less critical machines.
   j. Through the use of less space.
   k. Through the use of less in-production time.
2. Better product in respect to function or salability:
   This is a long range aspect of number 1, although it may involve greater cost of operation on a particular job. It may, however, in many situations be accomplished with less cost and is then doubly desirable.
3. Better material control:
   This is also an economic objective as it relates to inventory cost, scheduling and control functions, and customer service.

* For industries or activities other than manufacturing these criteria may need to be restated; i.e., in department store work as with other service occupations, customer service is of extreme importance; in medical work, patient safety assumes increased importance, etc. Adapted from Mundel, *Motion and Time Study: Principles and Practice*, pp. 27-28.

TABLE 5.13 CHECK LIST FOR PROCESS CHART—PRODUCT ANALYSIS*

Basic Principles

A. Reduce number of steps
B. Arrange steps in best order
C. Make steps as economical as possible
D. Reduce handlings
E. Combine steps if economical
F. Shorten moves
G. Provide most economical means for moving
H. Cut in-process inventory to workable minimum
I. Use minimum number of control points at most advantageous places

1. Can any step be eliminated?
   a. as unnecessary (Ask: Why is it done?)
   b. by new equipment (Ask: Why is present equipment used?)
   c. by changing the place where it is done or kept (Ask: Why is it done there?)
   d. by changing the order of work (Ask: Why is it done in its present order?)
   e. by changing the product design (Ask: Why is it done as it is?)
   f. by changing the specifications of the incoming supply (Ask: Why is it ordered in its present form or used at all?)
2. Can any step be combined with another?
   Are there any possible changes that would make this feasible in
   a. workplace
   b. equipment
   c. order of steps
   d. product design
   e. specification of supply or any raw material
3. Can the steps be rearranged so as to make any shorter or easier?
4. Can any step be made easier?
   (If this looks like a possibility, make further detailed analysis of this step. Analyses for this purpose will be discussed in later chapters.)

* From Mundel, *Motion and Time Study: Principles and Practice*, p. 56.

TABLE 5.14 CHECK LIST FOR PROCEDURE ANALYSIS

1. Each step should be necessary. If not, eliminate it.
2. Each step should have a reason for being by itself. Can it be combined?
3. Each step should have an ideal place in sequence. Where should it be?
4. Each step should be as easy as possible.
5. Each form should have a real purpose. Verify it. Is the form necessary? Can it be eliminated, combined with another form, or replaced by a copy of another form?
6. Files should have a purpose. Do they? Avoid duplication. Avoid excess files. File by subject used to enter files. Check on manner of use.
7. If form is finally destroyed; it should never, in some cases, have been originated.
8. Information going from one form to another suggests more copies in the first place. Are all information take-offs and readings necessary? If so, which are going to be given priority for design.
9. Are all copies getting equal use? Sharing the load may speed up the procedures.
10. Does someone sign all copies? How can this be avoided? Signers are busy.
11. Is there excess checking?
12. Where is the best place to check? Calculate the risk.
13. What would happen if a form was lost?
14. What equipment might help the job? (See commercial catalogs.)
15. Does one person have too much of the procedure.
16. Are as many steps as possible given to the lowest classification personnel applicable?
17. Can travel of forms be advantageously reduced?
18. Can the form be kept in action, out of file baskets?

TABLE 5.15 CHECK LIST FOR PROCESS CHART—MAN ANALYSIS*

Basic Principles

A. Eliminate all possible steps
B. Combine steps
C. Shorten steps
D. Place in best sequence
E. Make each step as economical as possible

1. Can any operation be eliminated, combined, shortened, or made easier?
   a. as unnecessary
   b. by changing the order of work
   c. by new or different equipment
   d. by changes in the layout; by grouping equipment better
   e. by changing the form of the product sent out
   f. by more knowledge on part of the worker
2. Can any movement be eliminated, combined, shortened, or made easier?
   a. by leaving out operations
   b. by changing the places where things are kept
   c. by shifting some operations to another job into which they fit more conveniently
   d. by changing the layout
   e. by changing equipment
   f. by changing the order of work
   g. by conveyors (make sure they are economical)
3. Can delays be eliminated, combined, or shortened?
   a. by changing the order of work
   b. by changing the layout
   c. by new or different equipment
4. Can countings or inspections be eliminated, combined, shortened, or made easier?
   a. Are they really necessary; what happens after they are done and the information obtained
   b. Do they provide unnecessary duplication
   c. Can they be performed more conveniently by another person
   d. Are they done at the best point in the sequence
   e. Can sample inspection or statistical control be used
5. Can any step be made safer?
   a. by changing the order of work
   b. by new or different equipment
   c. by changing the layout

* From Mundel, *Motion and Time Study: Principles and Practice*, p. 98.

TABLE 5.16 CHECK LIST FOR OPERATION CHART*

Basic Principles

- A. Reduce total steps to minimum
- B. Arrange in best order
- C. Combine steps where feasible
- D. Make each step as easy as possible
- E. Balance the work of the hands
- F. Avoid the use of the hands for holding

1. Can a suboperation be eliminated?
   - a. as unnecessary
   - b. by a change in the order of work
   - c. by a change of tools or equipment
   - d. by a change of layout of the workplace
   - e. by combining tools
   - f. by a slight change of material
   - g. by a slight change in product
   - h. by a quick-acting clamp on jig, if jigs are used
2. Can a movement be eliminated?
   - a. as unnecessary
   - b. by a change in the order of work
   - c. by combining tools
   - d. by a change of tools or equipment
   - e. by a drop disposal of finished material
     (The less exact the release requirements, the faster the release.)
3. Can a hold be eliminated? (Holding is extremely fatiguing.)
   - a. as unnecessary
   - b. by a simple holding device or fixture
4. Can a delay be eliminated or shortened?
   - a. as unnecessary
   - b. by a change in the work that each body member does
   - c. by balancing the work between the body members
   - d. by working simultaneously on two items
     (Slightly less than double production is possible with the typical person.)
   - e. by alternating the work, each hand doing the same job, but out of phase
5. Can a suboperation be made easier?
   - a. by better tools
     (Handles should allow maximum flesh contact without sharp corners for power; easy spin, small diameter for speed on light work.)

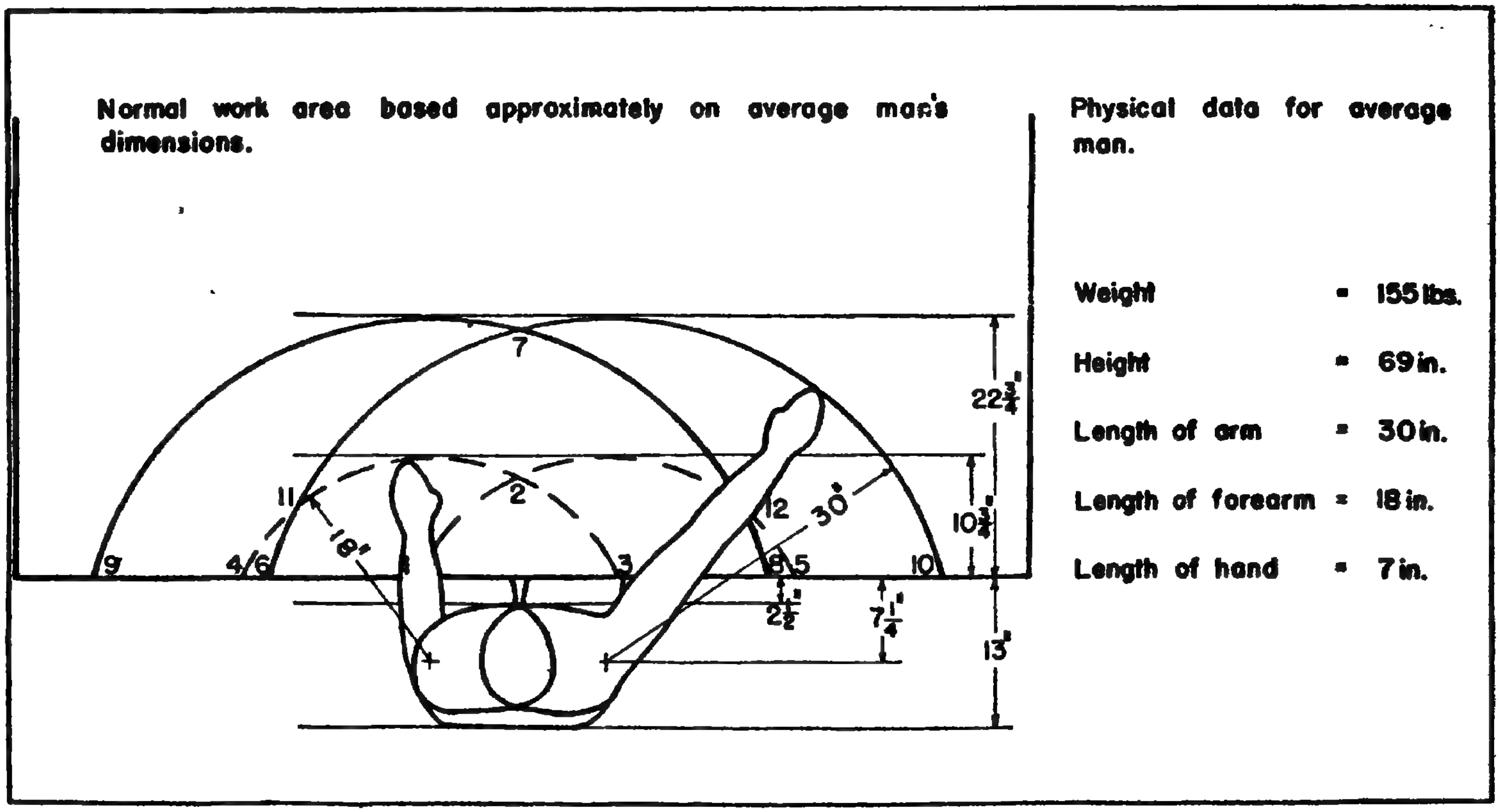
TABLE 5.16 (*Continued*)

b. by changing leverages
c. by changing positions of controls or tools
(Put into normal work area—Fig. 5.1
d. by better material containers
(Bins that permit slide grasp of small parts are preferable to bins that must be dipped into.)
e. by using inertia where possible
f. by lessening visual requirements
g. by better workplace heights
(Keep workplace height below elbow.)

6. Can a movement be made easier?
a. by a change of layout, shortening distances (see Fig. 5.1)
(Place tools and equipment as near place of use and as nearly in position of use as possible.)
b. by changing direction of movements
(Optimum angle of workplace for light knobs, key switches, and handwheels is probably 30° and certainly between 0° to 45° to plane perpendicular to plane of front of operator's body.—Unpublished Purdue Research)
c. by using different muscles
Use the first muscle group in this list that is strong enough for the task: (See Fig. 5.1 for visual items that may affect this order)
1. finger (not desirable for steady load or highly repetitive motions)
2. wrist
3. forearm
4. upper arm
5. trunk (for heavy loads shift to large leg muscles)
d. by making movements continuous rather than jerky
(See Fig. 5.1)

7. Can a hold be made easier?
a. by shortening its duration
b. by using stronger muscle groups, such as the legs, with foot-operated vises

* From Mundel, *Motion and Time Study: Principles and Practice*, pp. 153-154.



From Mundel, *Motion and Time Study: Principles and Practice*, p. 155.

FIG. **5.1** HUMAN WORK AREAS.

Preferred areas:

1. For work requiring visual direction:
   Best: 1-2-3
   Next: 2-11-7-12
   Next: 6-7-8
   Next: 4-11-7-12-5
2. For work with low visual requirements:
   Best: 4-11-2-12-5
   Next: 9-7-10

In all cases—attempt to keep within 9-7-10 to avoid trunk movements.

TABLE 5.17 CHECK LIST FOR MAN AND MACHINE CHARTS*

Basic Principles

A. Eliminate steps
B. Combine steps
C. Rearrange in best fashion
D. Make each step as easy as possible
E. Raise percentage of cycle of machine running time to maximum
F. Reduce machine loading and unloading to minimum
G. Raise machine speed to economic limit

(The first seven questions that follow are similar to those used with operation charts, where more detail was given; hence, the reader is also referred back to them. The bare questions are given here so as to provide at one place, all of the check-list items to be used.)

1. Can a suboperation be eliminated?
   a. as unnecessary
   b. by a change in the order of work
   c. by a change of tools or equipment
   d. by a change in layout of the workplace
   e. by combining tools
   f. by a slight change of material
   g. by a slight change in product
   h. by a quick-acting clamp on the jigs or fixtures
2. Can a movement be eliminated?
   a. as unnecessary
   b. by a change in the order of work
   c. by combining tools
   d. by a change of tools or equipment
   e. by a drop disposal of finished material
3. Can a hold be eliminated? (Holding is extremely fatiguing.)
   a. as unnecessary
   b. by a simple holding device or fixture
4. Can a delay be eliminated or shortened?
   a. as unnecessary
   b. by a change in the work each body member does
   c. by balancing the work between the body members
   d. by working simultaneously on two items
   e. by alternating the work, each hand doing the same job, but out of phase

5. Can a suboperation be made easier?
    a. by better tools
    b. by changing leverages
    c. by changing positions of controls or tools
    d. by better material containers
    e. by using inertia where possible
    f. by lessening visual requirements
    g. by better workplace heights
6. Can a movement be made easier?
    a. by a change of layout, shortening distances
    b. by changing the direction of movements
    c. by using different muscles (see Fig. 5.1)
       Use the first muscle group in this list that is strong enough for the task:
        1. finger
        2. wrist
        3. forearm
        4. upper arm
        5. trunk
    d. making movements continuous rather than jerky
7. Can a hold be made easier?
    a. by shortening its duration
    b. by using stronger muscle groups, such as the legs, with foot-operated vises
8. Can the cycle be rearranged so that more of the handwork can be done during running time?
    a. by automatic feed
    b. by automatic supply of material
    c. by change of man and machine phase relationship
    d. by automatic power cut-off at completion of cut or in case of tool or material failure
9. Can the machine time be shortened?
    a. by better tools
    b. by combined tools
    c. by higher feeds or speeds

* From Mundel, *Motion and Time Study: Principles and Practice*, pp. 175-176.

TABLE 5.18 CHECK LIST FOR MULTI-MAN AND MULTI-MAN AND MACHINE PROCESS CHARTS*

Basic Principles

A. Balance the work of the crew
B. If a machine is involved, consider increasing percentage of use
C. Ease the job of the most-loaded man
D. Eliminate steps
E. Combine steps
F. Make steps as easy as possible

1. Can any operation be eliminated?
   a. as unnecessary
   b. by changing the order of work
   c. by new or different equipment
   d. by changes in the layout
2. Can any movement be eliminated?
   a. by leaving out operations
   b. by shifting some operations to another job into which they fit more conveniently
   c. by changing equipment
   d. by changing the layout
   e. by changing the order of work
   f. by conveyors (Make sure they are economical.)
3. Can delays be eliminated?
   a. by changing the order of work
   b. by changing the layout
   c. by new or different equipment
4. Can countings or inspections be eliminated?
   a. Are they really necessary; what happens after they are done and the information obtained
   b. Do they give unnecessary duplication
   c. Can they be performed more conveniently by another person
   d. Are they done at the best point in the sequence
5. Can operations be combined?
   a. by changing the order of work
   b. with new or different equipment
   c. by changing the layout
6. Can movements be combined?
   a. by changing the order of work
   b. by changing the layout
   c. by changing the quantity handled at one time
7. Can delays be combined?
   a. by changing the order of work
   b. by changing the layout
   c. if they provide rest, can they be grouped better
8. Can countings or inspections be combined?
   a. by changing the order of work
   b. by changing the layout
9. Can any step be made safer?
   a. by changing the order of work
   b. by new or different equipment
   c. by changing the layout
10. Can any operation be made easier?
    a. by a better tool
    b. by changing positions of controls or tools
    c. by using better material containers or racks, bins, or trucks
    d. by using inertia where possible and avoiding it where worker must overcome it

e. by lessening visual requirements (see Fig. 5.1)
f. by better workplace heights
g. by using different muscles (see Fig. 5.1)
Use the first muscle group in this list that is strong enough for the task:
1. finger
2. wrist
3. elbow
4. shoulder
5. trunk
h. by jigs or fixtures

11. Can any movement be made easier?
a. by a change in layout, shortening distances
b. by a change in the direction of movements
c. by changing its place in the sequence to one where the distance that must be traveled is shorter

12. Can any delay of one crew member, caused by another crew member, be eliminated?
a. by changing the number on the crew
b. by changing the number of machines that the crew uses
(One must again bear in mind the following four possibilities, which were listed previously in connection with man and machine charts.)
1. Reduction of operator delays to the minimum required for rest and personal time. There may be considerable machine delay.
2. Reduction of machine delays to the minimum required to provide the operator with rest and personal time, at which times the machine is unattended. There may be considerable other operator delay.
3. Reduction of machine and operator delays such that they will provide the most economical balance.
4. Reduction of both operator and machine delays to the minimum required to provide the operator with rest and personal time.
c. by a redistribution of the work among the crew
d. by changing the order of work of the crew

* From Mundel, *Motion and Time Study: Principles and Practice*, pp. 200-201.

TABLE 5.19 CHECK LIST FOR THERBLIGS

Basic principles

1. Try to have both hands doing the same thing at the same time or balance the work of the two hands.
2. Try to avoid the use of the hands for holding.
3. Keep the work in the normal work area. (See Fig. 5.1.)
4. Relieve the hands of work whenever possible.
5. Eliminate as many therbligs or as much of a therblig as possible.
6. Arrange the therbligs in the most convenient order.
7. Combine therbligs when possible.
8. Standardize method and train worker.

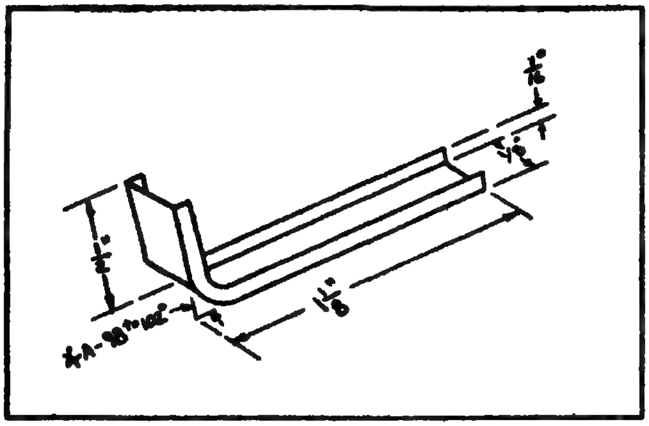
	Examine				
Therblig	Design of product	Tools	Jigs	Workplace layout and equipment	Motion pattern
G	Easy to pick up No hazard	Combine Pre-position Assign place Design for grasp In holders	Easy to take parts from or self-ejecting If portable, design for grasp	Ejecting bins Lip bins Slide bins PP boxes No barriers to vision Tool holders Tweezers or tongs	Avoid hand to hand grasp PP parts Slide parts Use bins to advantage Use best type of grasp
P and PP	Less weight Maximum tolerances Bevel holes Round tops of pins Bevel screw ends Make parts for easy line-up Easy access Remove burrs	Self-guiding or locating Easy grip Good leverage Pre-position in holders	Hold parts at convenient angles Receive parts from convenient TL path Stops, guides, funnels Maximum tolerance in jig Large locking motion Self-locating for parts	Paint for seeing Maximum PP of tools and material Arrange for easy TL to place of P and PP	Natural, free motions with accuracy supplied by stops Combine P with TL Combine several P's into one

U, A, and DA	Minimum tool work Reduce screw lengths Easy to get at Combine parts Subassemble Remove burrs	Power Ratchets Combined tools PP tools Design for task Easy to use Best leverage Utilize momentum	Allow free action of tools Guide tools Bevel bushings Bullet top on locating pins Hold parts firmly Uniform type of fastening, preferably clamp levers At convenient height and angle Rotatable Few fastenings	Not in way of tools Tool holders Convenient height	Natural motions Lightest muscle group able to do job Proper leverage Proper posture Back brace on chair Combine U's and A's
RL	Droppable Easy to let go of	Suspended or in PP holder at all times	Easy to fit parts into Will automatically locate parts Kick, blow, drop, slide, or spring parts out	Chutes for RL near work area or in TL path Self-counting trays	As soon as possible Foot ejector As part of TL Without P
TE and TL	Fewer parts Less weight	Within easy reach Light Easy to hold Balanced Counterbalanced Self-returning Foot control	Near parts Chutes and drops Make following P less exacting Attach levers, wheels, and wrenches	Arrange parts for natural sequence Get parts and tools close to point of use	Use smooth continuous motions, circular paths, avoid backtracking Co-ordinate with use of eyes Use both hands systematically Use smallest amount of body required Two or more parts at once provided this does not interfere in subsequent P

TABLE 5.19 *(Continued)*

Therblig	Examine				
	Design of product	Tools	Jigs	Workplace layout and equipment	Motion pattern
SH and ST	Standardize parts Make nontangling Color code	Not tangle with other tools Minimum number Special eyeglasses Combine Paint in contrasting color Pre-position Definite location	Fixed in place Levers or wrenches attached Paint controls in contrasting color	Lip bins Definite places for tools and materials Label or color bins Bins contrast with parts Illuminate workplace Paint workplace for seeing	Use eyes to do work Use uniform motion pattern Use bins or trays of material systematically
H, UD, and AD	See basic rules. These therbligs are undesirable. Balanced work with machine cycle if machine is used.				
R	If other therbligs are improved this will be reduced to a minimum. Rest is preferably provided by a rest pause rather than as a regular element in the cycle. If it occurs as part of a machine operation, it should take place during machine running time.				
PN	See basic rules. This therblig is undesirable. Balance work with machine cycle if machine is used.				
I	Easy reference points Minimum requirements	Easy reading Go-no-go Optical Rugged Combined gages	Minimum number of fastenings Uniform fastenings Light Built-in gages Easy reading	Good light, free of glare and flicker; of proper color, direction, and contrast	Fixed and definite pattern even for eyes Arrange so part is stationary when being viewed

From Mundel, ***Motion and Time Study: Principles and Practice***, pp. 246-249.



From Mundel, *Motion and Time Study: Principles and Practice*, p. 38.

FIG. 5.2 ARMATURE ARM.

3.8 FORMS AND ILLUSTRATIONS

Because of space requirements, a simple illustration has been given in each case. As the complexity of the problem increases, the advantage of the graphic technique as an aid to understanding also increases.

3.8.1 For establishing *Aim*. The forms given are only samples. In practice, many versions exist.

Possibility list and guide. A possibility list for the manufacture of an armature arm (see Fig. 5.2) is given in Fig. 5.3. Here the possibilities and the classes of change affected are listed, but not the consequences. A form for detailing the consequences is shown in Fig. 5.4.

Activity chart: Fig. 5.5. Work distribution chart: Figure 5.6.

Machine load chart: This type of chart is similar to that shown in Fig. 5.5, but the machine rather than the person is the subject.

Functional form analysis chart: Fig. 5.7.

3.8.2 For *Analysis*. Sample forms for both product and man analysis techniques are given. In practice, many variations exist.

3.8.2.1 For product analysis. Only simple cases are shown, in the form in which they would appear in practice.

Process chart—product analysis: A simple process chart—product analysis of a materials handling problem is shown in Fig. 5.8. An improved method is shown in Fig. 5.9. A more complex type of chart is shown in Fig. 5.10. This type is sometimes useful for the entire manufacture of a complex product. In preparing such a chart, a large ruled sheet or even a blank sheet of paper would be used in preference to a form. In other cases, a preprinted form such as that shown in Fig. 5.11 may be used. In the illustration given, a paper-work problem is being followed. Although paperwork is commonly analyzed in this manner, it is suggested that the method of Fig. 5.14 is preferable for paperwork.

Flow diagram: The original flow diagram of the process charted in Fig. 5.8 is shown in Fig. 5.12, and the improved method is shown in Fig. 5.13.

Procedure analysis chart: A simple procedure analysis chart showing the activity with forms and of the personnel concerned with the forms is shown in Fig. 5.14. Although the charts for complex procedures may become rather large, they greatly facilitate understanding, study, discussion, and improvement. Indeed, without charting, some procedures defy understanding.

3.8.2.2 For man analysis. Samples of the various charts are given as they would appear in practice. In actual use, of course, many varieties appear.

Process chart—man analysis: An original process chart—man analysis is given in Fig. 5.15. The improved version shown in Fig. 5.16 resulted from applying the check list in Table 5.15.

Type of Chart Preliminary Possibility Guide

Method Present process — Machine No. ——

Operation Mfg. — Operation No. ——

Criterion Lower cost — Part No. 124R

Part name Armature Arm — Chart by L. Edmond

Operator —— — Date charted 2/16/46

Suggestion Number	Class of Change	Description	Other classes affected
1	5	Use sheet stock	4, 3, 2, 1
2	5	Purchase formed to size and shape	3, 2, 1
3	4	Redesign relay to allow more tolerance in arm eliminating inspection	3, 2, 1
4	3	Inspect at punch press as part of operation	2, 1
5	2	Dual inspection fixture, electric response	1
6	1	Tip fixture to make easier, weigh to count at inspection	
7	1	Distribute work to both hands at inspection	

If more space is needed paste additional sheet on here.

From Mundel, *Motion and Time Study: Principles and Practice*, p. 39.

FIG. **5.3** POSSIBILITY LIST.

POSSIBILITY GUIDE

Name of ~~Operation~~ Mfg. Process, Armature Arm - 124 R

Operation Number ——

File Number 124-R

Analysis by L. Edmond

Date 2/16/46

Class of Change	Hand and Body Motions	Tools, Workplace and Equipment	Process	Product Design	Raw Material
1	Distribute work to both hands on inspection	Tip fixture Scale to weigh count (on inspection).			
2	Balanced hand pattern	Dual inspection fixture, electric response (See above also)			
3	Fit into pattern of press operation	Fixture convenient for press operator	Inspect at punch press as part of operation		
4	Check assembly motions for effect of redesign	Check assembly fixtures for effect of tolerance	Eliminate inspection From press send to assembly	Redesign relay to allow more tolerance in arm	
5	Eliminated No inspection See box above, the.	No equipment Simple die to blank, no forming	No process Eliminate inspection	No change shape, no channel	Purchase formed Sheet stock instead of channel

FIG. 5.4 POSSIBILITY GUIDE.

From Mundel, *Motion and Time Study: Principles and Practice*, p. 40.

G. Shaya NAME
24 March 1953 DATE
Mngt. Office UNIT
GS-2 GRADE

ACTIVITY CHART

Nature of activity	Remarks	Time began	Work units produced	Elap. time (min.)
Soundscriber transcription	Short letters	8^{00}	2 letters	30
" "	Type	8^{30}	1 report	120
Break		10^{30}		10
Run ditto	new stencils	10^{40}	2 stencils 50 each	10
Proof from Soundscriber	Report from 10^{20}	10^{50}	1 report	30
Type from handwrit. copy	Letters	11^{20}	2 letters	40
Lunch		12^{00}		60
Type from hand. copy	Letters	1^{00}	*	120
Break		3^{00}		10
Type from hand copy	Letters * (con't)	3^{10}	15 letters	110
Finish		5^{00}		
Summary				
1. Type letters from soundscriber			2	30
2. Type and proof report from soundscriber			1	150
3. Type letters from handwritten copy			17	270
4. Run ditto			2 stencils 50 each	10
5. Breaks			2	20
	TOTAL			480

From "Techniques of Work Simplification," *Dept. of Army*, Pamphlet No. 20-300, June, 1951.

FIG. 5.5 ACTIVITY CHART.

WORK DISTRIBUTION CHART
(DA Pamphlet 20-300)

Organizational unit charted: Assignment Section
☒ Existing organization ☐ Recommended organization
Charted by: Major Wilson
Approved by:
Date:

Activity Number	Activity	Work Count	Hours per Week	J. R. Wilson, Section Chief, Major — Tasks	Work Count	Hours per Week	Paul Smith, Chief Clerk, Sgt — Tasks	Work Count	Hours per Week	Wm. Chase, Strength Analyst, GS 7 — Tasks	Work Count	Hours per Week	Miss Hall, Order Clerk, GS 5 — Tasks	Work Count	Hours per Week	Miss Brown, Steno, GS 4 — Tasks	Work Count	Hours per Week	Miss Jones, Clerk-typist, GS 3 — Tasks	Work Count	Hours per Week
1.	Assignment of Enlisted Personnel	100	53	Allocates replacements to units	100	7	Assembles strength and requirements data		14	Recommends allocations		7	Prepares & proofreads transfer orders	100	13	Proofreads orders	100	7			
				Allocates levies from higher authority		5															
2.	Assignment of Officer Personnel	50	49	Studies requirements against authorizations		4	Checks rosters and records for completeness		8	Recommends allocations		4	Prepares & proofreads transfer orders	50	9	Proofreads orders	50	5	Drafts transfer orders	50	11
				Review assignments allocations		3															
				Approves orders	50	3															
3.	General Inquiry and Information Service		34	Conference with commanders and staff officers		3	Answers routine inquiries by phone	25	6	Presents studies to other branch officials		5	Routine inquiries on status of orders	10	5	Prepares records of branch conferences		6	Answers routine inquiries	7	3
				Review and sign letters of inquiry		1										Dictation & transcription of inquiry letters		5			
4.	Specific Case Studies & Requirements Analysis		48	Continuing survey of long-range requirements		3	Reviews Case Studies		3	Statistical Analysis of Unit Strength		12	Furnish data on personnel or orders		6	Dictation and transcription of case studies		8	Types summaries of requirements		8
				Review case studies		2				Studies scarce MOS categories		6									
5	Administration and Supervision		39	Conference with branch personnel		1	Time and Attendance records	6	4	Staff conference		2	Staff conference		2	Records of Staff Conferences		4	Types Weekly transfer summaries		11
				Prepare Budget		4	Prepare Administrative reports	3	2				Prepare Weekly Summaries of transfers		3				Types Administrative reports		4
				Staff Conferences		2															
6	Miscellaneous Activities		17				Analyses reports from other sections		3	Security Inspections		4	Special Messenger Service		2	Phone Directory Office SOP, etc.		5	Community Chest, Blue Cross, etc.		3
	Totals		240			40			40			40			40			40			40

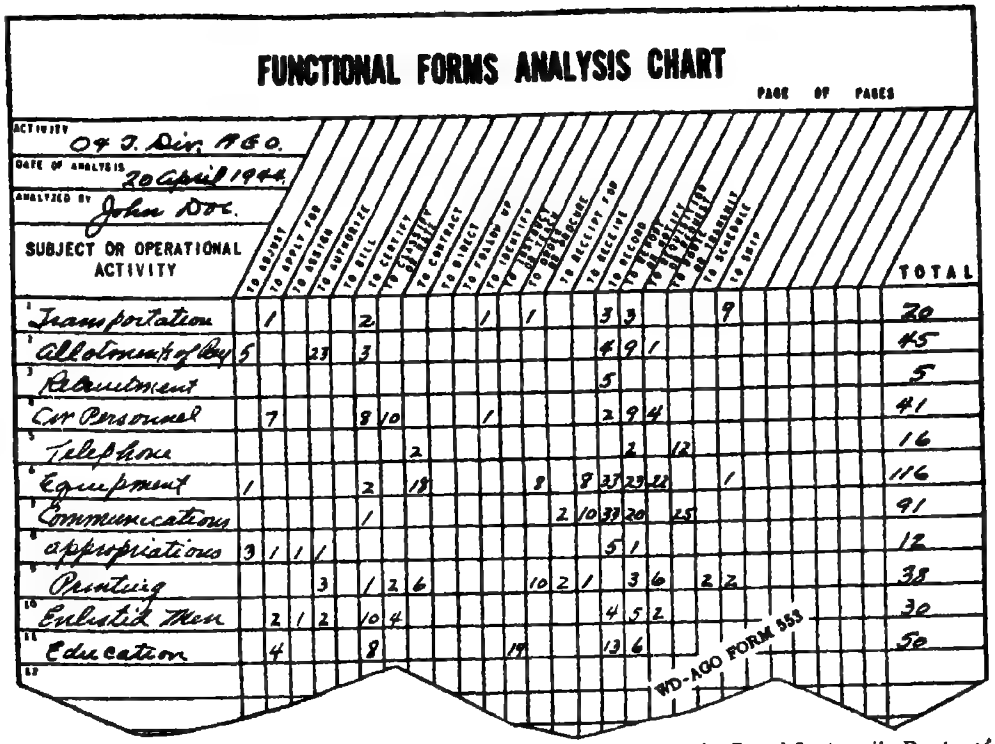
ANALYSIS: WHAT TAKES THE MOST TIME? ..IS THERE MISDIRECTED EFFORT? ...ARE SKILLS USED PROPERLY? ...ARE THERE TOO MANY UNRELATED TASKS? ..ARE TASKS SPREAD TOO THINLY? ...IS WORK DISTRIBUTED EVENLY?

DA FORM 673

Figure 3 Work Distribution Chart

FIG. 5.6 WORK DISTRIBUTION CHART.

From "Techniques of Work Simplification," *Dept. of Army*, Pamphlet 20-300, June, 1951.



From "Techniques of Work Simplification," *Dept. of Army*, Pamphlet 20-300, June, 1951.

FIG. **5.7** FUNCTIONAL FORMS ANALYSIS CHART.

Four general situations are encountered in applying process charts—man analysis.

1. *The work has a single repeated cycle.* Here a cycle is defined as all the steps necessary to bring a unit of product to the state of completion typical of the operation, or as all the steps typical of a single performance of the task. A single cycle is charted.
2. *The work is cyclic, but includes several subcycles performed with different frequencies.* For instance, the worker may perform subcycle A on each part and then subcycle B for ten parts together. The chart will show one performance of each subcycle and will also indicate its frequency.
3. *The work varies from cycle to cycle.*
   A. Some variations result from operator habit rather than from the inherent nature of the job (as in some maintenance work). Consequently, the analyst may have to plot several cycles in order to get enough material from which to develop a preferable work pattern.
   B. Other variations are inherent in the job. Each performance may differ in detail but not in general pattern. In such a case, sample cycles are drawn to indicate the general pattern and the varying details. The factors controlling the variation are weighted approximately.

   In either A or B, the application of the more complex memomotion study may be useful.
4. *The work is non-cyclic.* This is usually true of supervisory and similar activities. Here the chart may lead only to general suggestions for improved planning.

Man flow diagram: A man flow diagram corresponding to the job shown in Fig. 5.15 is given in Fig. 5.17.

Operation chart. A simple operation chart for the original method of drilling

Type of Chart: PROCESS CHART - PRODUCT ANALYSIS

Method: ORIGINAL Machine No: ~

Operation: TRUCKING Operation No: ~

Part No. 700-216

Part name: REFRIGERATOR SHELVES Chart by: Creech

Operator: ~ Date charted: 2-49

Quantity	Distance	Symbol	Explanation
X crates		▽	Bulk storage - Foundry
4 crates	100'	∘	By Buda truck - Dept. 136 trucker
80 crates		▽	Daily bank - Dept. 45
1 crate	100'	∘	By hand truck - Dept. 54 trucker
10 crates		▽	Hourly bank - Dept. 54
1 crate		○	Open crate - Dept. 54 trucker
100 shelves		▽	In crate
100 shelves	15'	∘	By hand truck - Dept. 54 trucker
100 shelves		▽	Automatic plater loading area

Summary

○	1
∘	3
▽	5
Dist.	215'

If more space is needed paste additional sheet on here

From Mundel, *Motion and Time Study: Principles and Practice*, p. 60.

FIG. 5.8 PROCESS CHART—PRODUCT ANALYSIS FOR ORIGINAL METHOD OF HANDLING REFRIGERATOR FOOD SHELVES FROM BULK STORAGE TO PLATING DEPARTMENT.

Type of Chart: PROCESS CHART – PRODUCT ANALYSIS
Method: PROPOSED — Machine No: ~
Operation: TRUCKING — Operation No: ~
Part No: 700 216
Part name: REFRIGERATOR SHELVES — Chart by: Creech
Operator: ~ — Date charted: 2-49

Quantity	Distance	Symbol	Explanation
X crates		▽	Bulk storage – Foundry
1 crate	15	•	By hand truck – Dept 54 trucker
1 crate		○	Open crate – Dept. 54 trucker
100 shelves		▽	In crate
100 shelves	60'	•	By hand truck – Dept. 54 trucker
100 shelves		▽	Automatic plater loading area

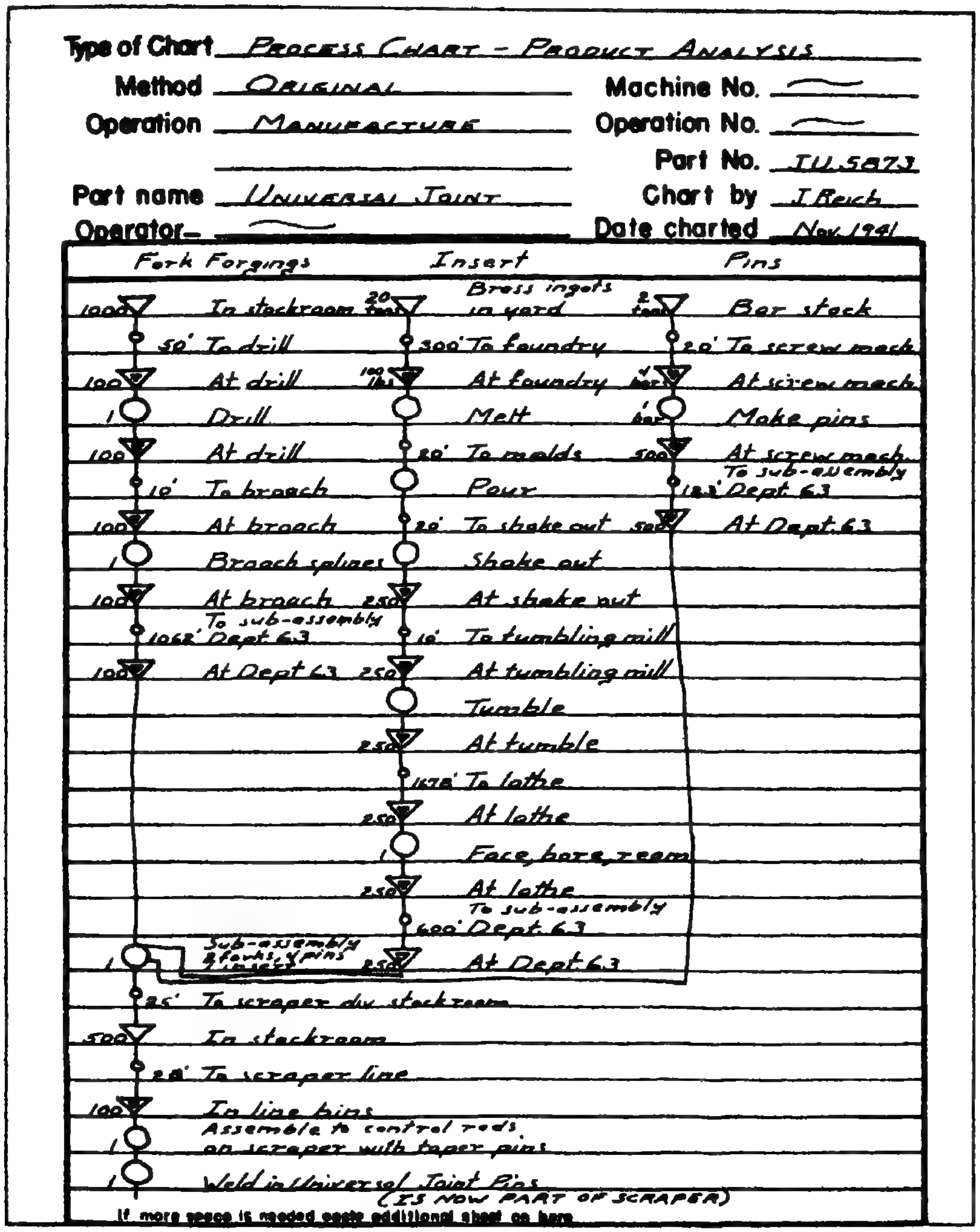
Summary & Recap.

	Original	Proposed	Saved
○	1	1	0
•	3	2	1
▽	5	3	2
Dist.	215'	75	140

If more space is needed paste additional sheet on here

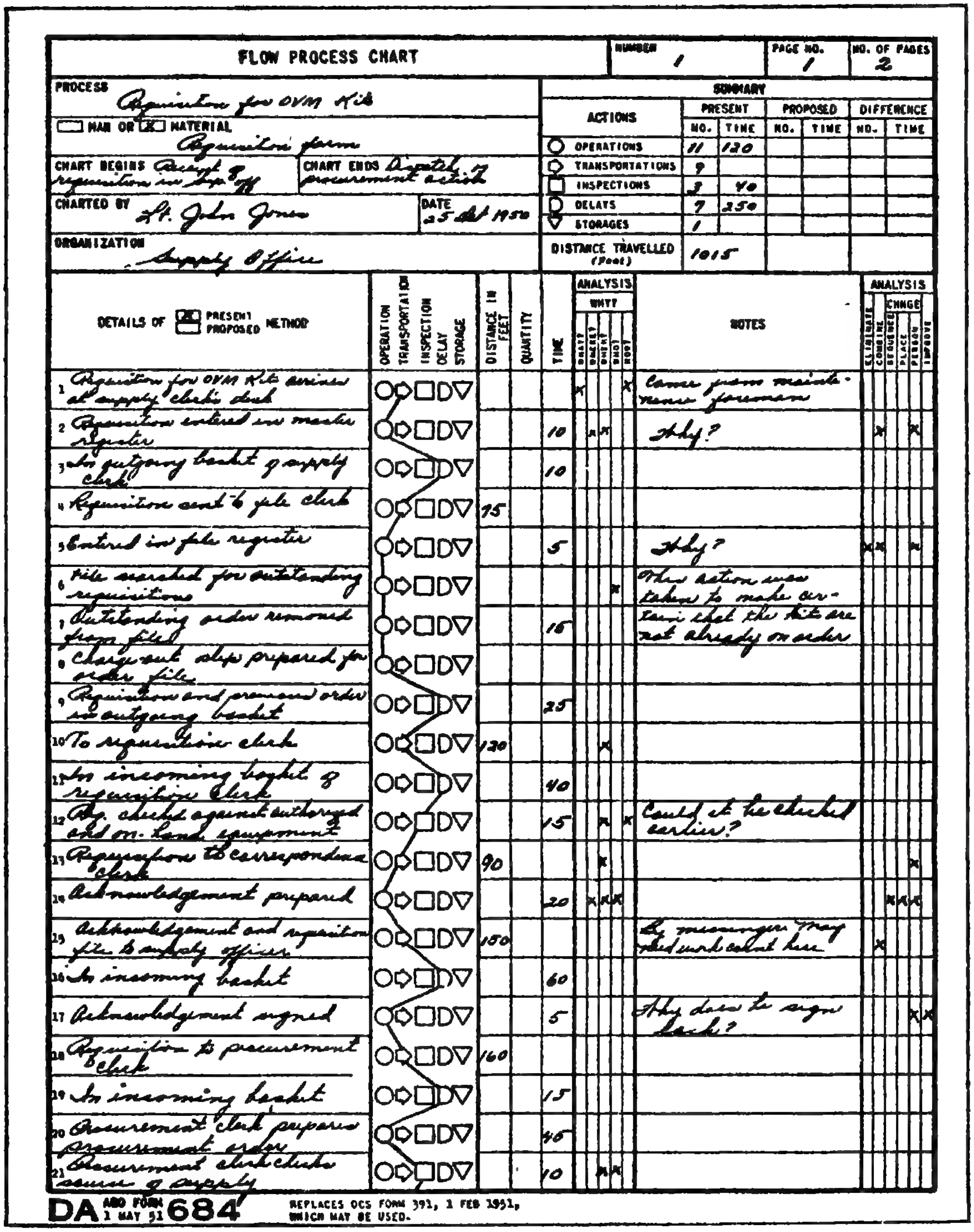
From Mundel, *Motion and Time Study: Principles and Practice*, p. 62.

FIG. 5.9 PROCESS CHART—PRODUCT ANALYSIS FOR IMPROVED METHOD OF PROCESS OF FIG. 5.8.



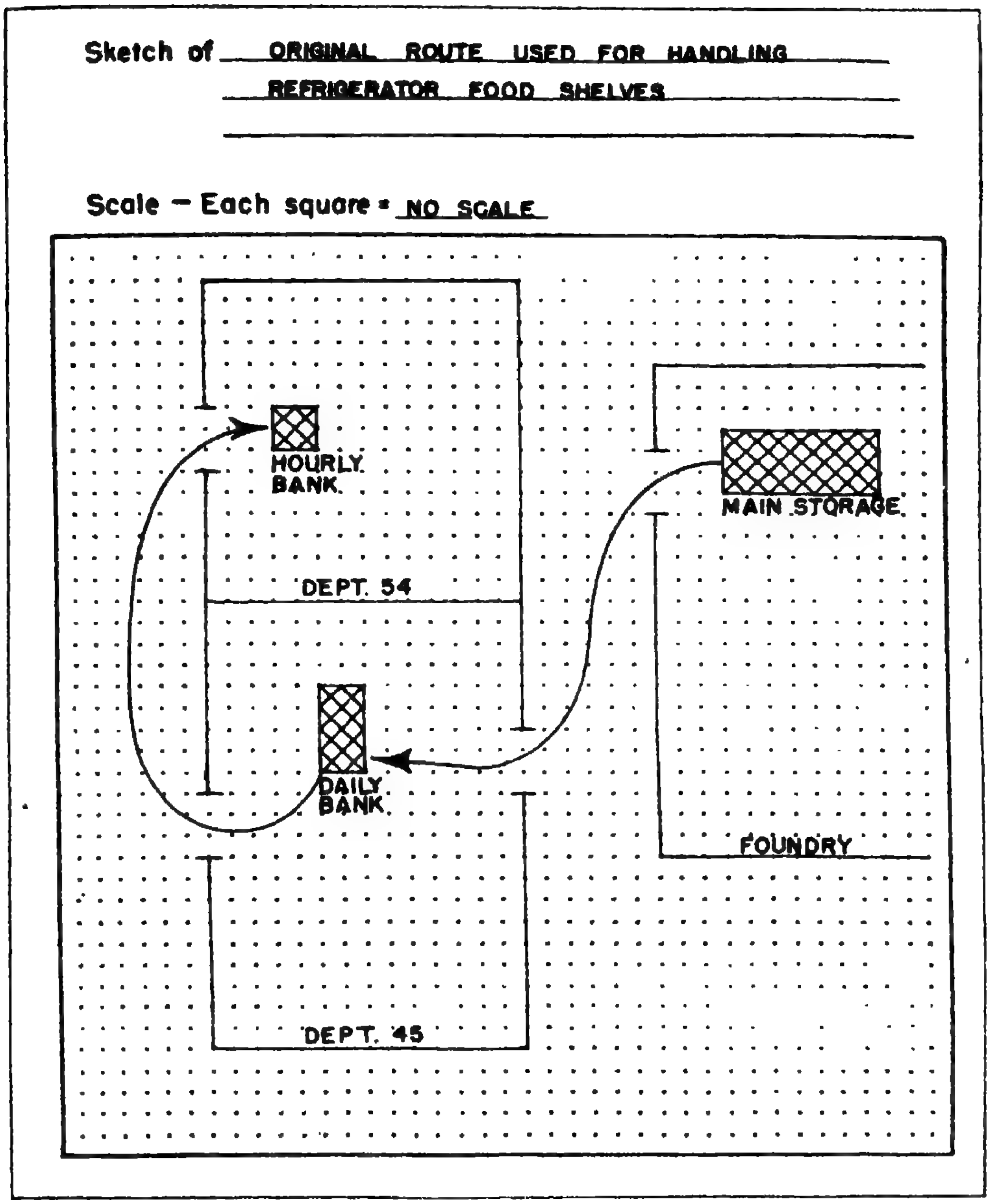
From Mundel, *Motion and Time Study: Principles and Practice*, p. 86.

FIG. **5.10** PROCESS CHART—PRODUCT ANALYSIS FOR PROPOSED METHOD OF MANUFACTURE OF UNIVERSAL JOINT.



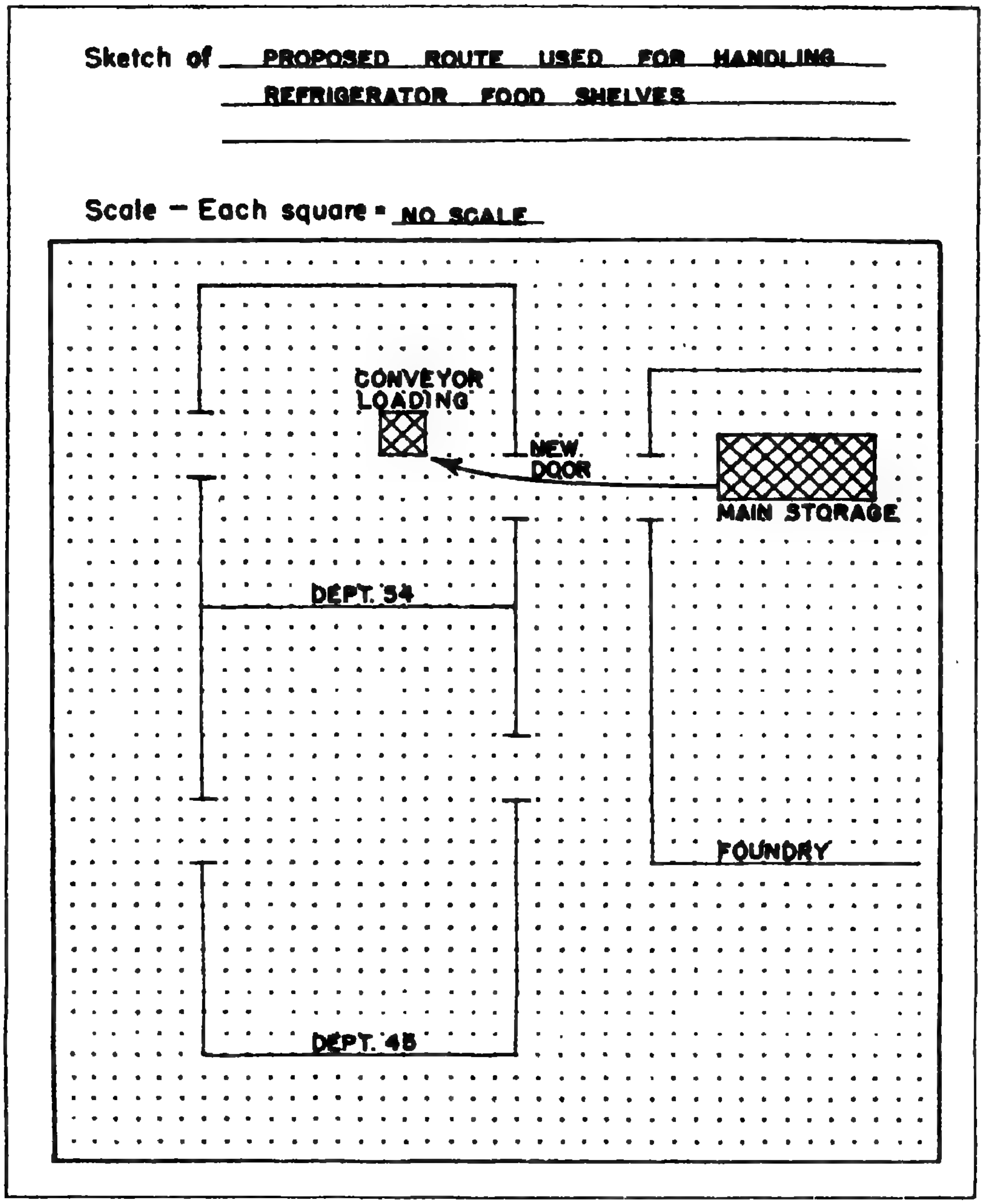
From "Techniques of Work Simplification," *Dept. of Army*, Pamphlet No. 20-300, June, 1951.

FIG. **5.11** PROCESS CHART—PRODUCT ANALYSIS USING PREPRINTED FORM.



From Mundel, *Motion and Time Study: Principles and Practice*, p. 61.

FIG. **5.12** FLOW DIAGRAM FOR PROCESS CHARTED IN FIG. 5.8.



From Mundel, *Motion and Time Study: Principles and Practice*, p. 63.

FIG. 5.13 FLOW DIAGRAM FOR PROCESS CHARTED IN FIG. 5.9.

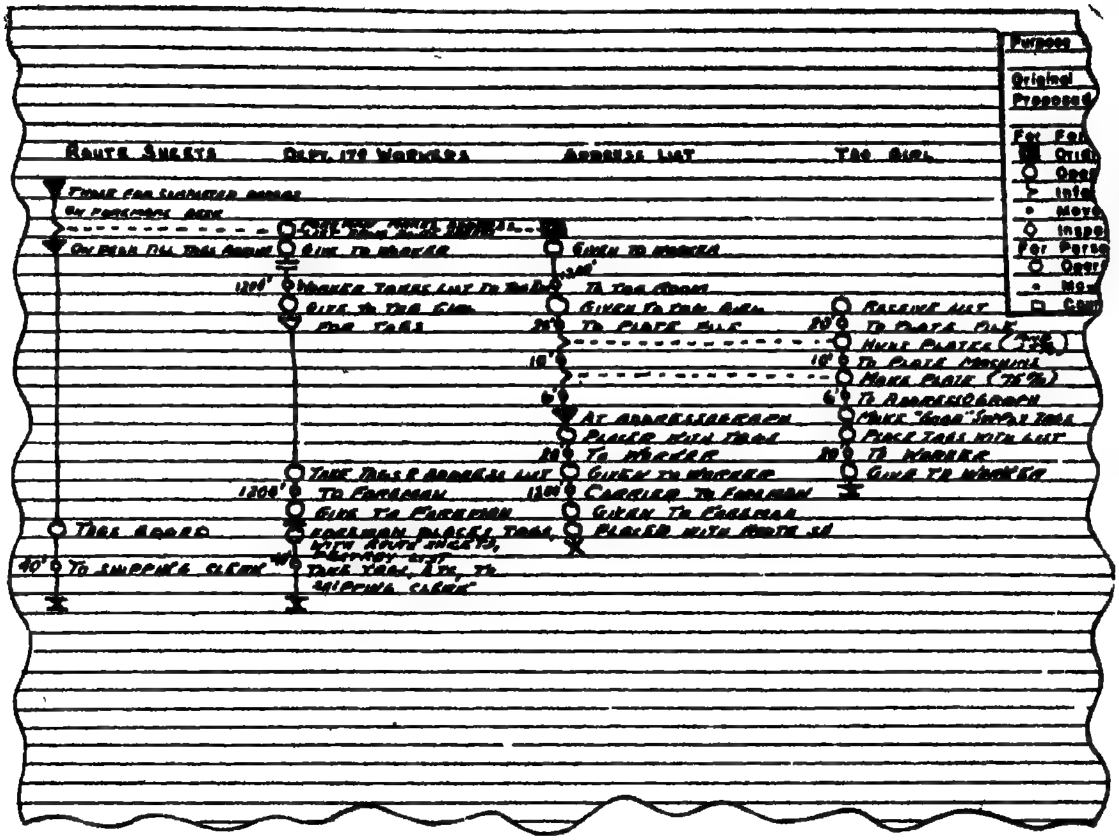


FIG. 5.14 PROCEDURE ANALYSIS CHART (SECTION).

hinge channels is shown in Fig. 5.18. The workplace is shown in Fig. 5.19 and the hinge channel itself in Fig. 5.20.

As with process charts—man analysis, four types of jobs, with the following characteristics, may be encountered:

1. The work has a single repeated cycle.
2. The work is cyclic, but there are several subcycles performed with different frequency.
3. The work varies from cycle to cycle.
4. The task is such that there is no regular cycle.

The method of handling these different types of jobs is essentially similar to the procedure used with process charts—man analysis, except that the work of the individual body members is studied rather than the worker as a whole.

Multiple activity. Sample charts are shown for the major types. Other forms may appear in practice. In extremely complex cases, large sheets of graph or tracing paper may be preferable to a ruled form.

Man and machine operation charts: A chart showing the original method of performing an operation on a centerless grinder is given in Fig. 5.21.

Man and machine operation time chart: The chart in Fig. 5.22 shows an improved method of performing the same operation shown in Fig. 5.21.

Man and machine process time chart: The chart in Fig. 5.23 shows the operation of wind, stretch, chop, and peel radio-tube grids with the aid of a grid lathe.

Multi-man and machine process chart: The chart in Fig. 5.24 shows the original method for a three-man crew cutting studs on a cut-off saw.

Multi-man and machine time charts: The chart in Fig. 5.24 shows an improved method for performing the same operation shown in Fig. 5.25.

For micromotion study. Many of the charts previously described may be made with the aid of micromotion study. Three

Type of Chart PROCESS CHART—MAN ANALYSIS

Method	ORIGINAL	Machine No.	D-GROUP
Operation	INSPECT DRAWN COPPER WIRE	Operation No.	I-3
		Part No.	—
Part name	ALL DRAWN COPPER	Chart by	C.W. Mc.
Operator	SIMON GREEN	Date charted	6/46

DIST.	SYMBOL	DESCRIPTION
24'	∘	To next finished spool
	○	Take spool
24'	∘	To inspection bench
	○	Place spool on bench
	○	Strip and cut outer layer which is always damaged in drawing
15'	∘	To scrap container
	○	Dispose of scrap
15'	∘	To inspection table
	○	Cut 2' from end, then 2" sample from 2' piece
	◇	O.D. with box micrometer
	○	Pick up spool
24'	∘	To machine's "inspected" rack
	○	Place spool

SUMMARY

○	7
□	0
◇	1
∘	5
▽	0
DIST	102' AVG.

If more space is needed paste additional sheet on here.

From Mundel, *Motion and Time Study: Principles and Practice*, p. 95.

FIG. 3.15 PROCESS CHART—MAN ANALYSIS FOR ORIGINAL METHOD OF INSPECTING PRODUCTION OF COPPER WIRE.

Type of Chart PROCESS CHART-MAN ANALYSIS

Method PROPOSED — Machine No. D-GROUP

Operation INSPECT DRAWN COPPER WIRE — Operation No. I-3

Part No. —

Part name ALL DRAWN COPPER — Chart by C.W. Mc

Operator—BASED ON GREEN — Date charted 6/46

DIST.	SYMBOL	DESCRIPTION
20′	∘	To next finished spool with bench
	○	Take spool
	○	Place on bench
	○	Strip, cut and sample
	○	Dispose of scrap in container attached to bench
	◇	O.D. with box micrometer
4′	∘	Bench to "inspected" rack
	○	Pick up spool
	○	Place spool

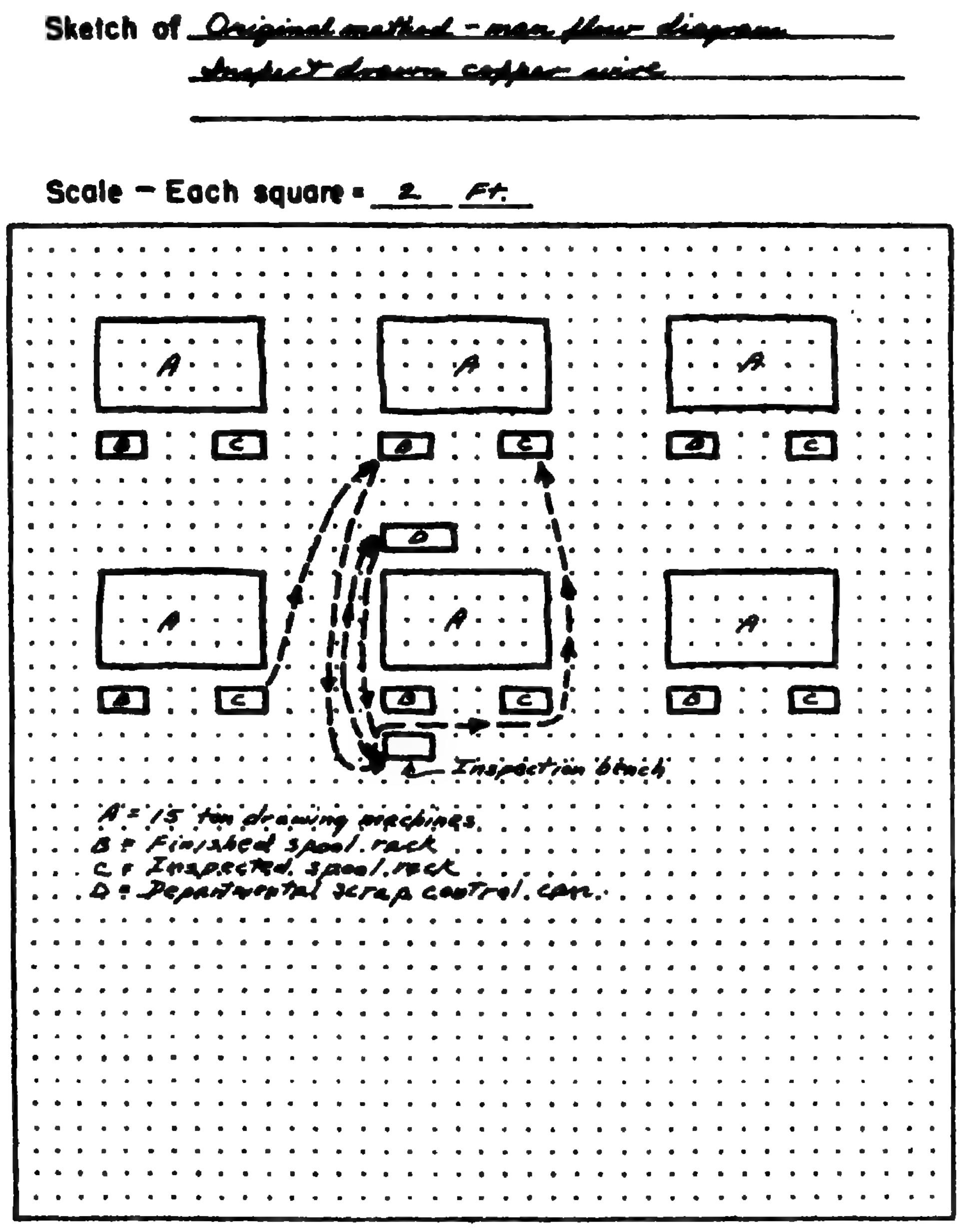
SUMMARY AND RECAPITULATION

	PROPOSED	ORIG.	SAVED
○	6	7	1
□	0	0	0
◇	1	1	0
∘	2	5	3
▽	0	0	0
DIST	24′ AVG.	102′ AVG.	78′ AVG.

If more space is needed paste additional sheet on here

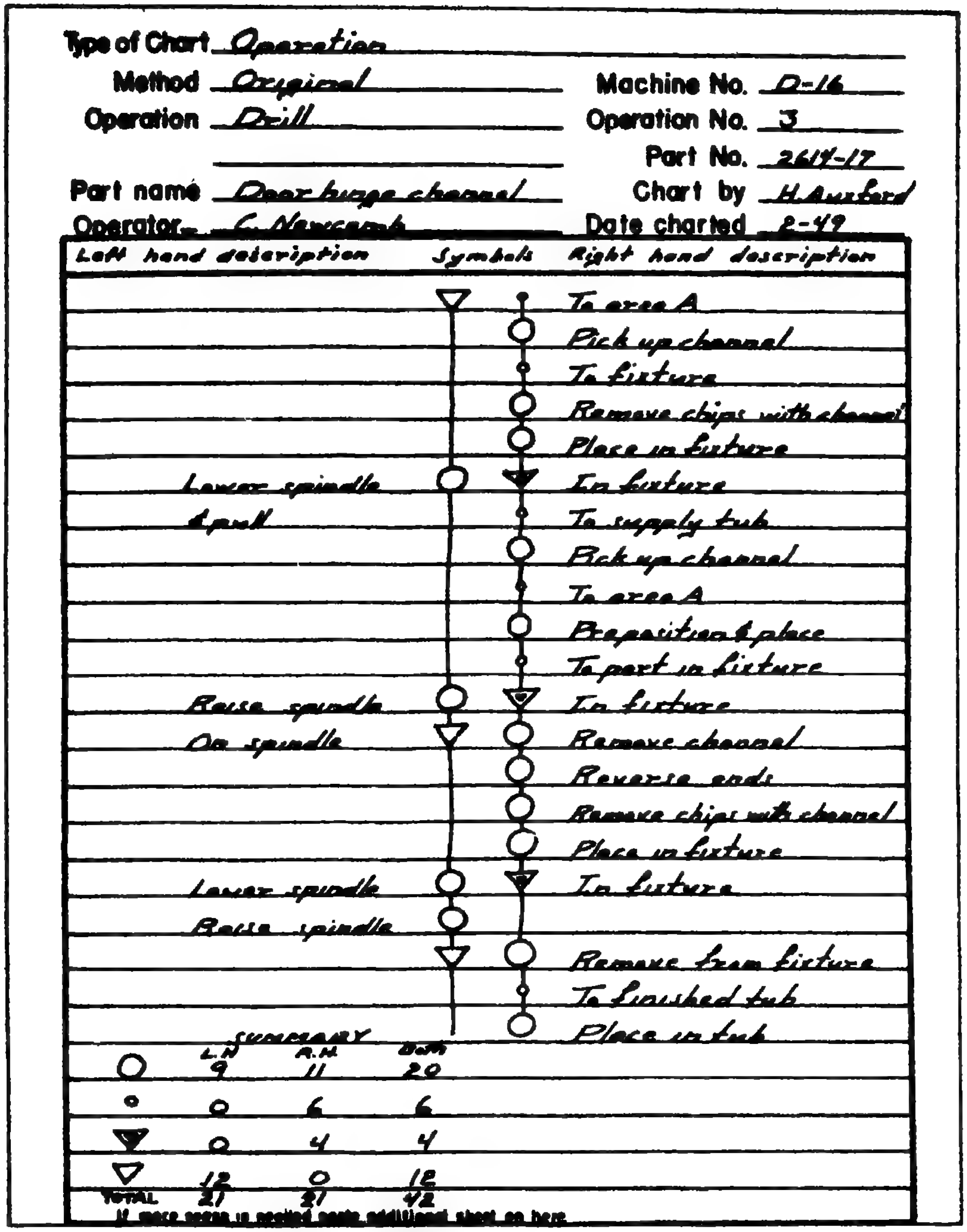
From Mundel, *Motion and Time Study: Principles and Practice*, p. 99.

FIG. 5.16 PROCESS CHART—MAN ANALYSIS FOR IMPROVED METHOD OF JOB CHARTED IN FIG. 5.15.



From Mundel, *Motion and Time Study: Principles and Practice*, p. 96.

FIG. 5.17 MAN FLOW DIAGRAM FOR ORIGINAL METHOD OF INSPECTING PRODUCTION OF COPPER WIRE.



Type of Chart Operation

Method	Original	Machine No.	D-16
Operation	Drill	Operation No.	3
		Part No.	2614-17
Part name	Door hinge channel	Chart by	H. Ausford
Operator	C. Newcomb	Date charted	2-49

Left hand description	Symbols		Right hand description
	▽	•	To area A
		○	Pick up channel
		•	To fixture
		○	Remove chips with channel
		○	Place in fixture
Lower spindle	○	▼	In fixture
drill		•	To supply tub
		○	Pick up channel
		•	To area A
		○	Preposition & place
		•	To part in fixture
Raise spindle	○	▼	In fixture
On spindle	▽	○	Remove channel
		○	Reverse ends
		○	Remove chips with channel
		○	Place in fixture
Lower spindle	○	▼	In fixture
Raise spindle	○		
	▽	○	Remove from fixture
		•	To finished tub
		○	Place in tub

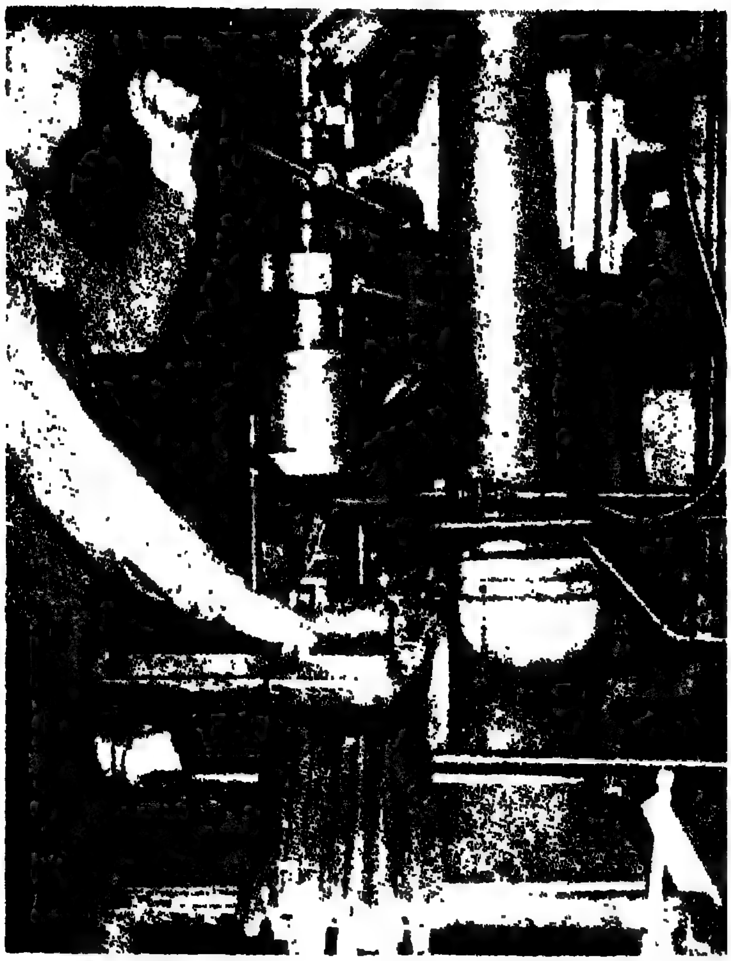
SUMMARY

	L.H.	R.H.	Both
○	9	11	20
•	0	6	6
▼	0	4	4
▽	12	0	12
TOTAL	21	21	42

If more space is needed paste additional sheet on here

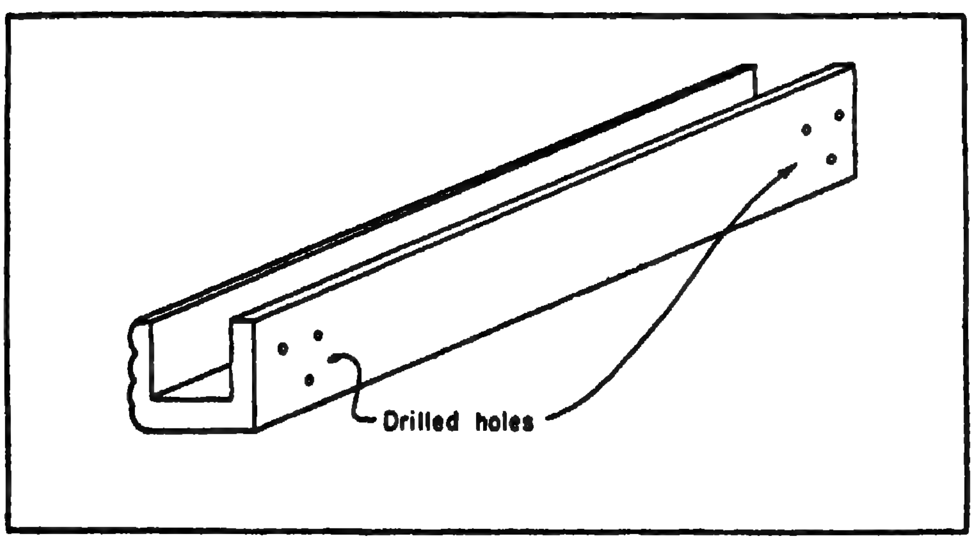
From Mundel, *Motion and Time Study: Principles and Practice*, p. 164.

FIG. **5.18** ORIGINAL OPERATION CHART FOR DRILL HOLES IN HINGE CHANNEL.



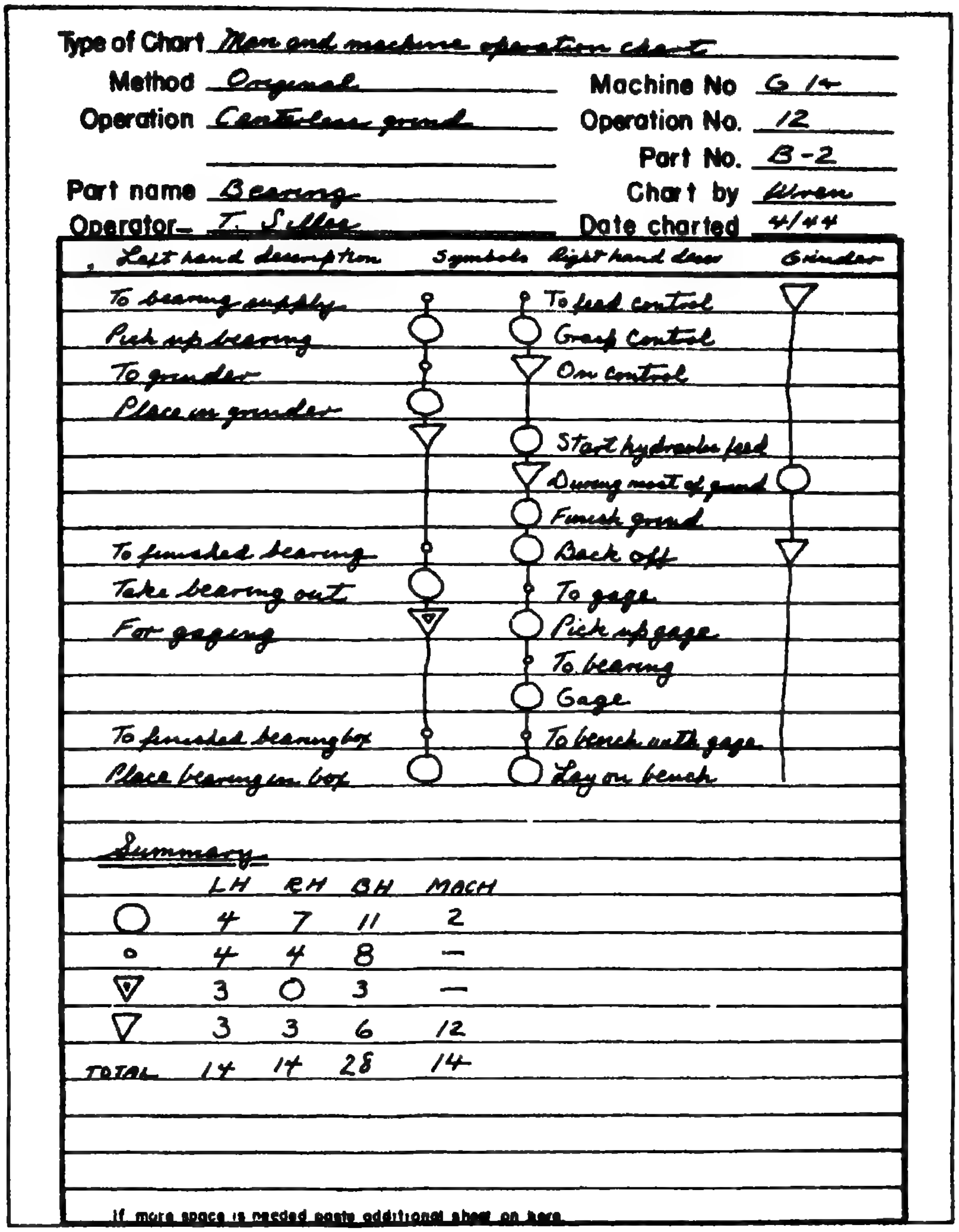
From Mundel, *Motion and Time Study: Principles and Practice*, p. 165.

FIG. **5.19** WORKPLACE FOR DRILL HINGE CHANNEL.



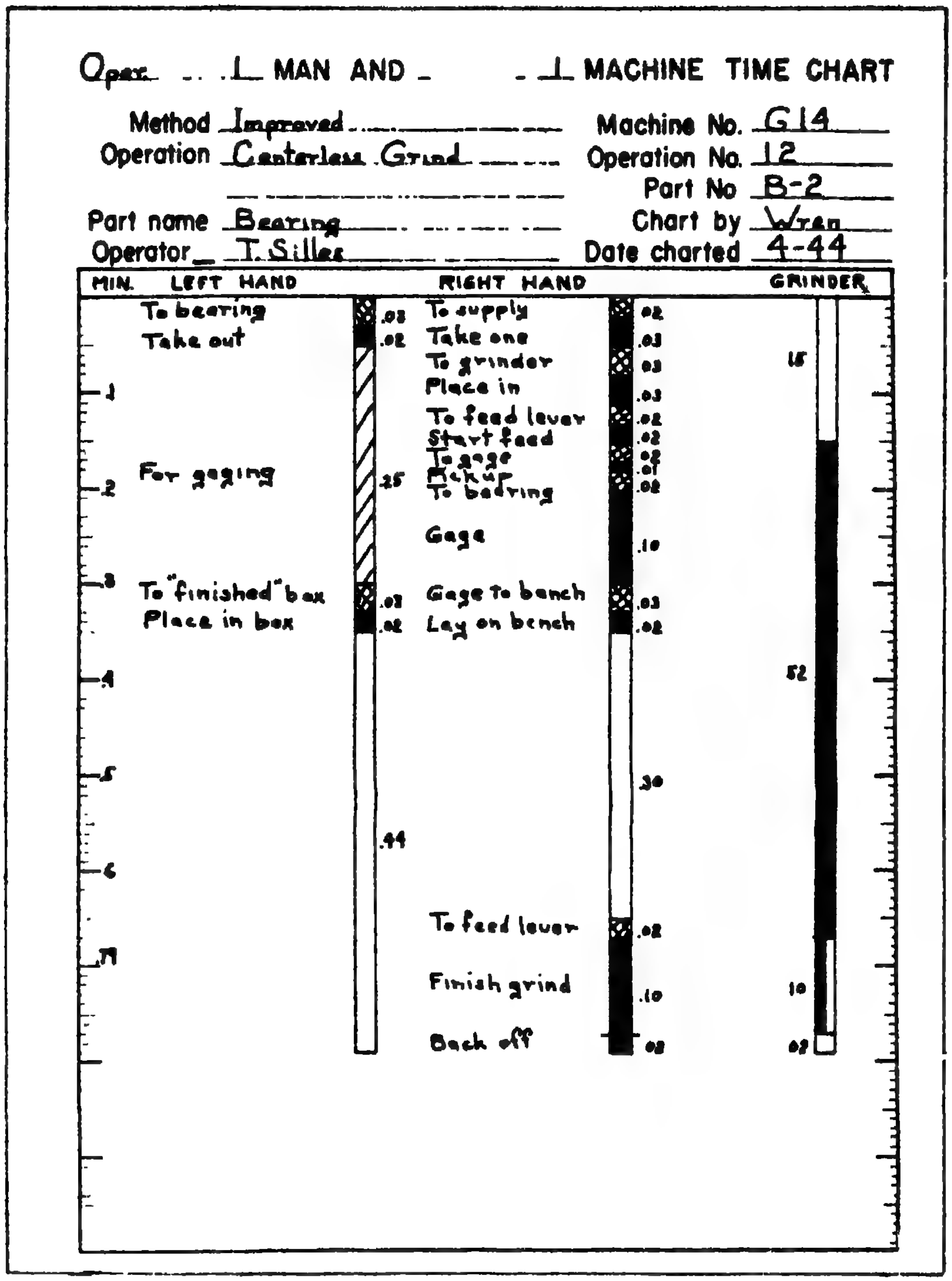
From Mundel, *Motion and Time Study: Principles and Practice*, p. 165.

FIG. **5.20** HINGE CHANNEL.



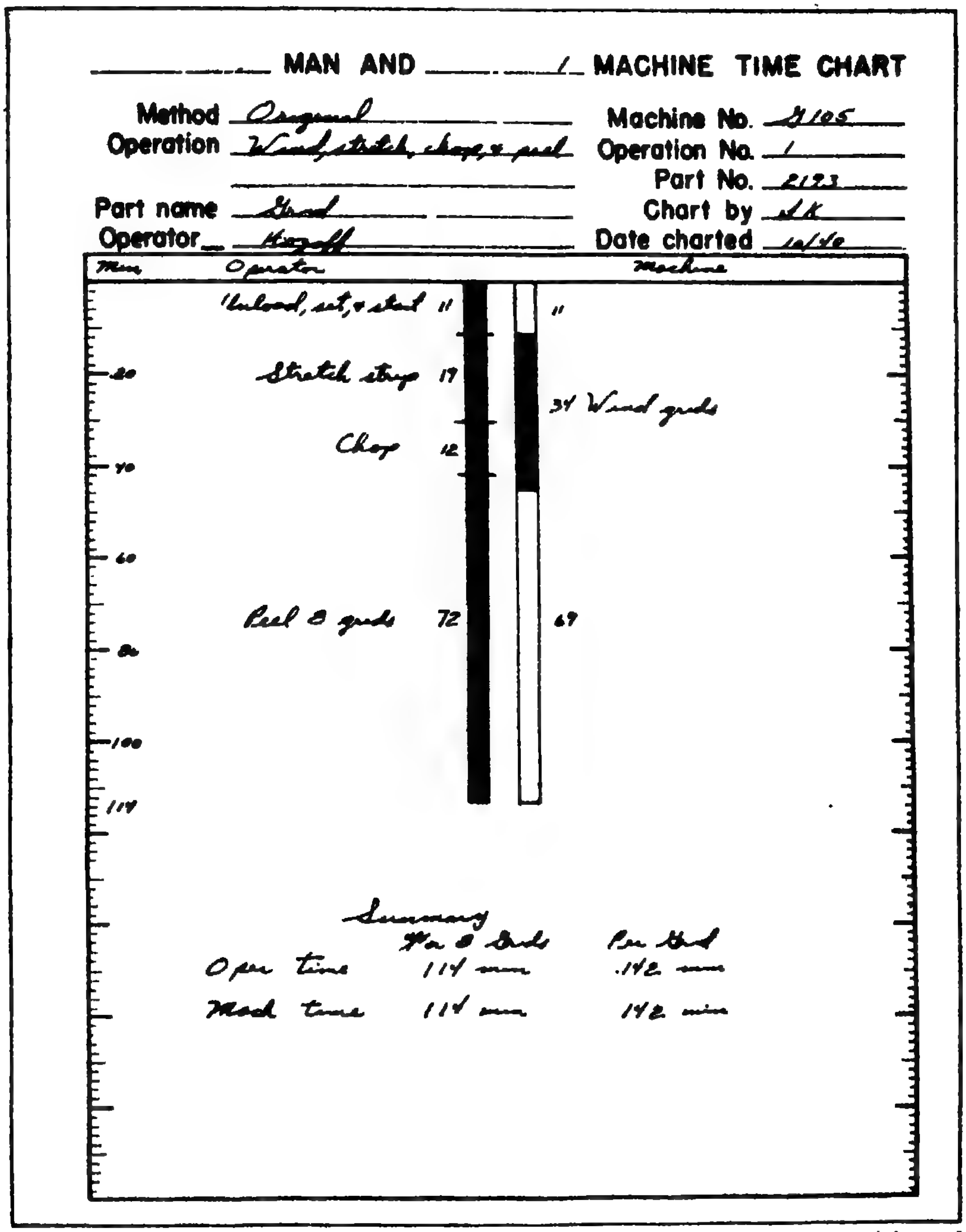
From Mundel, *Motion and Time Study: Principles and Practice*, p. 172.

FIG. **5.21** MAN AND MACHINE OPERATION CHART FOR ORIGINAL METHOD OF CENTERLESS GRIND AIRCRAFT-ENGINE BEARING.



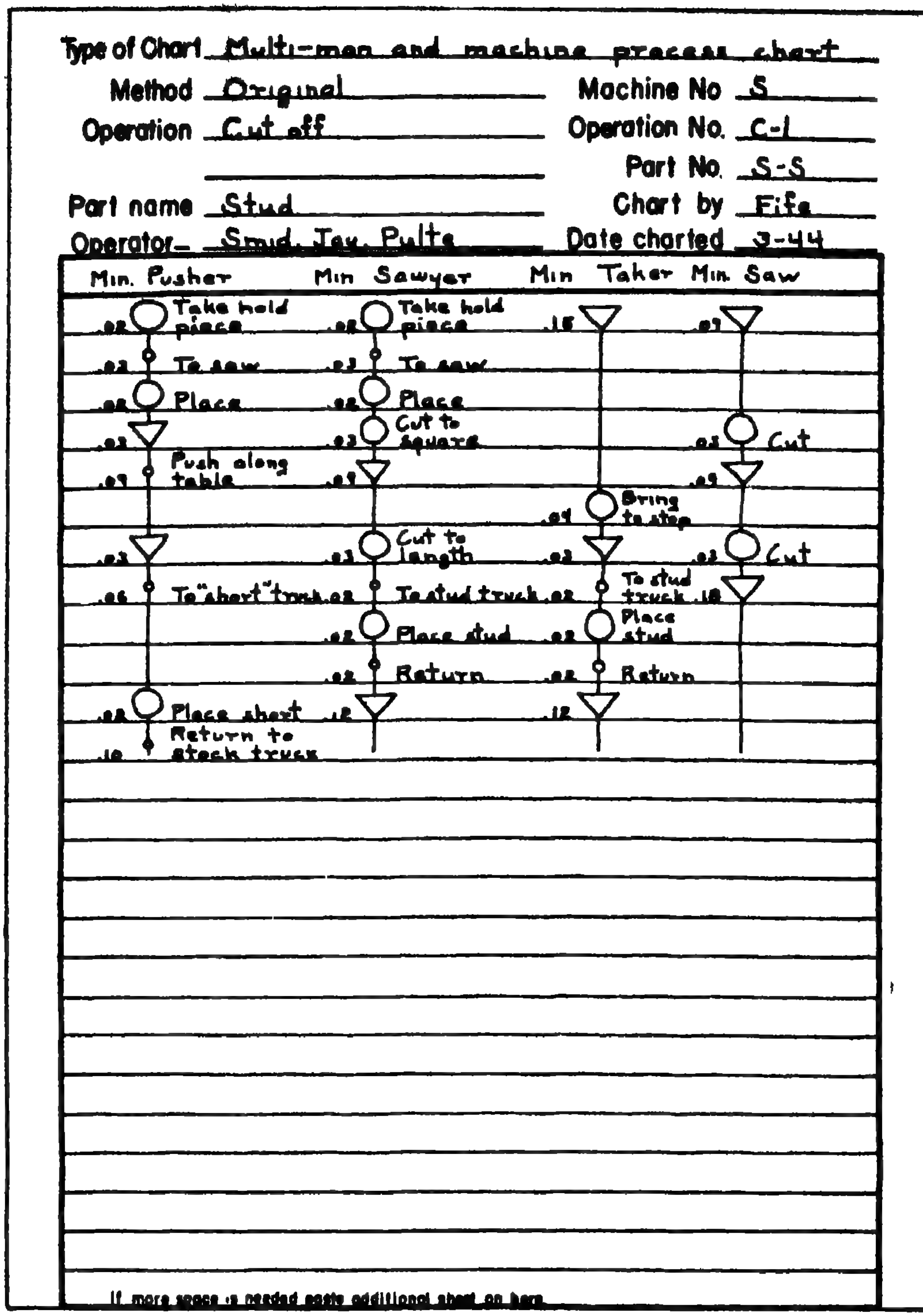
From Mundel, *Motion and Time Study: Principles and Practice*, p. 182.

FIG. 5.22 MAN AND MACHINE OPERATION TIME CHART FOR IMPROVED METHOD OF CENTERLESS GRIND AIRCRAFT-ENGINE BEARING.



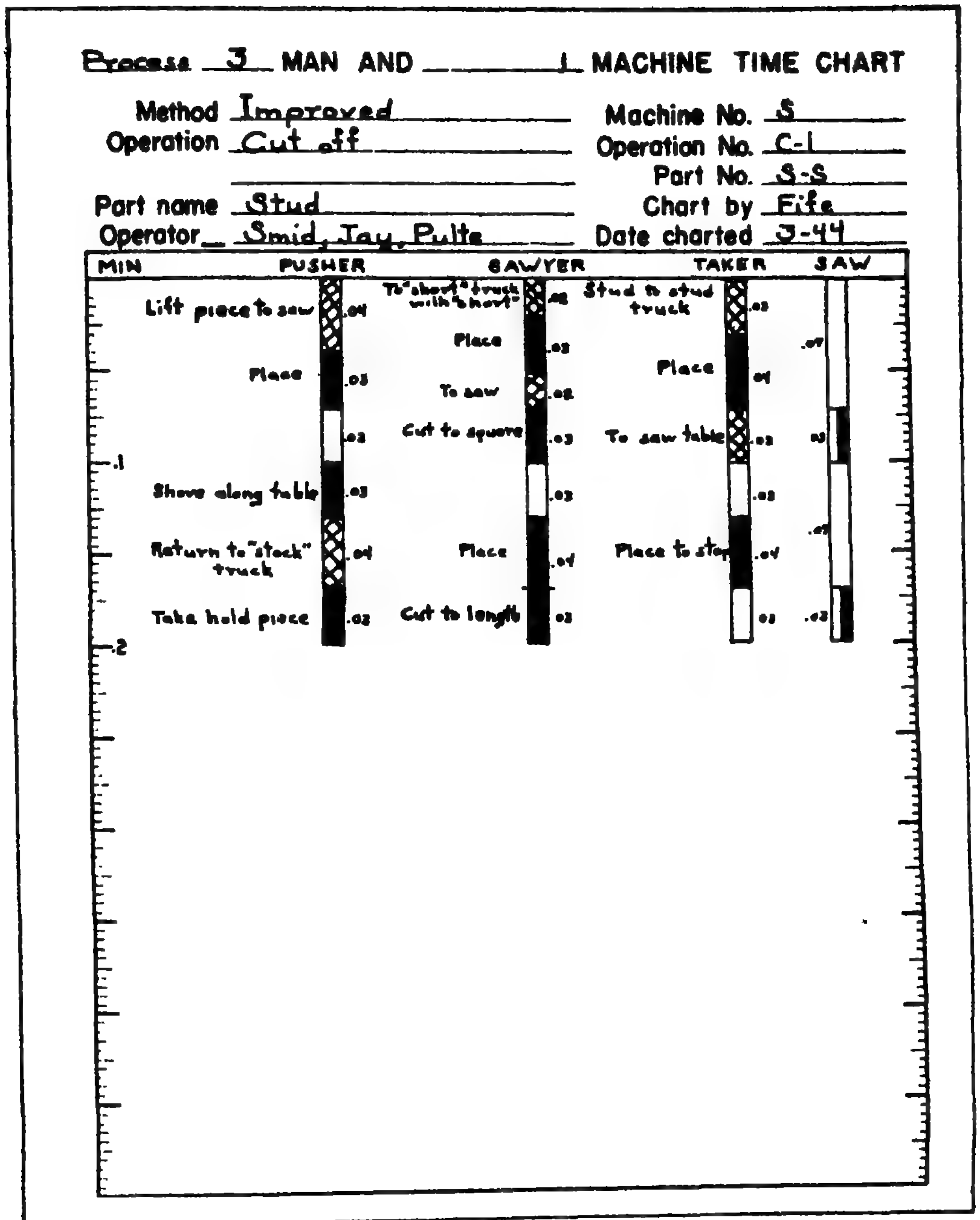
From Mundel, *Motion and Time Study: Principles and Practice*, p. 188.

FIG. **5.23** MAN-AND MACHINE-PROCESS TIME CHART FOR ONE-MAN CREW ON WINDING, STRETCHING, CHOPPING AND PEELING RADIO-TUBE GRIDS.



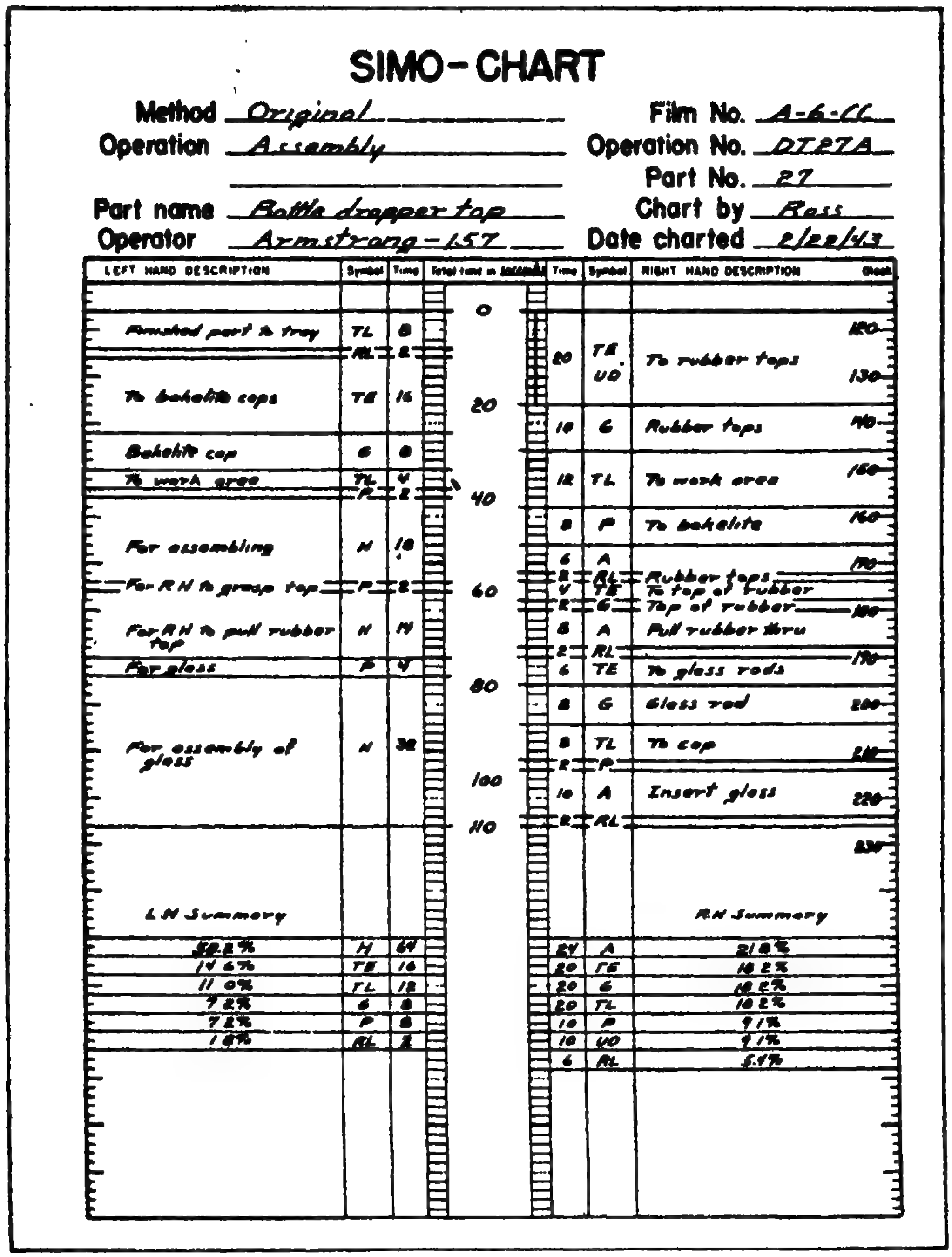
From Mundel, *Motion and Time Study: Principles and Practice*, p. 198.

FIG. **5.24** MULTIMAN AND MACHINE PROCESS CHART FOR ORIGINAL METHOD OF THREE-MAN CREW CUT 8′ LENGTH FROM 14′ 2″ x 4″ LUMBER.



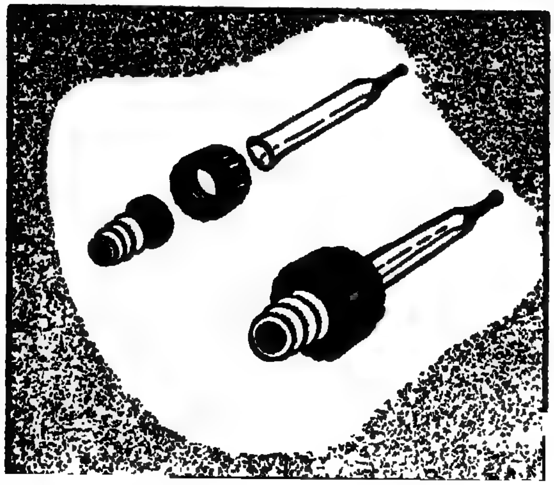
From Mundel, *Motion and Time Study: Principles and Practice*, p. 199.

FIG. **5.25** MULTIMAN AND MACHINE PROCESS TIME CHART FOR IMPROVED METHOD OF JOB OF FIG. 5.24.



From Mundel, *Motion and Time Study: Principles and Practice*, p. 244.

FIG. 5.26 SIMO-CHART FOR ORIGINAL METHOD OF ASSEMBLING DROPPER BOTTLE TOPS.



From Mundel, *Motion and Time Study: Principles and Practice*, p. 241.

FIG. **5.27** PARTS OF MEDICINE-BOTTLE DROPPER TOP AND ASSEMBLY.

steps are involved: filming, film analysis, and charting.

Simo charts: A simo chart, with therbligs, for a simple assembly operation, is shown in Fig. 5.26. The parts are shown in Fig. 5.27. The form used to record the film data, including the workplace layout, is shown in Fig. 5.28. An analysis of the film of one cycle of the operation from which the chart was made is shown in Fig. 5.29.

Memomotion chart: Sections of a memomotion chart (a process time chart —man analysis) of a hotel maid cleaning a hotel room are shown in Fig. 5.30.

3.9 OUTLINES OF PROCEDURES

Procedures for the major techniques are outlined below to provide a general guide to use. Since the same graphic techniques are used for analysis, innovation (synthesis), and test, the outline for each technique indicates how it is used at each step.

3.9.1 For establishing *Aim*. The following outline indicates how a possibility guide is used. A similar procedure is followed with other related techniques.

1. Uses:
   a. Aids in systematically listing possible changes and in collecting material from which to determine an objective.
   b. Aids in determining a suitable analysis technique.
   c. Indicates which divisions in the organization will be affected.
2. How made:
   a. Either a form as shown in Fig. 5.3 or a blank sheet of paper may be used.
   b. The analyst states his criterion of success.
   c. The analyst determines roughly the degree of change that is warranted.
   d. With the aid of a check list, the analyst lists the possibilities that occur to him, tempering his imagination with the decision reached in the previous step, identifies each possibility as to class of change and other areas affected, and gives each possibility an identifying number.
   e. The analyst expands each possibility on a detailed possibility guide form, or on a blank sheet of paper, so that he may examine the consequences of each.
3. How used:
   a. Aided by his knowledge of business and manufacturing, and of the economic and psychological

MICROMOTION STUDY DATA SHEET

DT27A-3

Operation *Assemble dropper top*

No *DT27A*

Method No *AWSP-2*

Film No *3*

Operation No *DT27A*

Operator No *157*

Part Name *Dropper top*

Part No *37*

Date *2/16/43*

By *Ledoum*

CAMERA DATA

Camera Name *Victor C 3*

Lens Name *Wollensak Velostigmat*

Focal Length *1"*

Max f No *1.5*

Frames per sec		Exposure
8	☐	1/15 sec
16	☒	1/30
24	☐	1/45
32	☐	1/60
48	☐	1/90
64	☐	1/120
96	☐	1/180
128	☐	1/240
1	☐	1/12 (Cine memo drive)

FILM, LIGHT AND EXPOSURE

Film *Eastman Super XX*

Weston - Day *80*

Tung *64*

Light Reading *13*

On *Work area*

Aperature f *6.3*

Clock *Telechron*

Focus *6* ft. *0* in.

To *Clock*

SYMBOLS

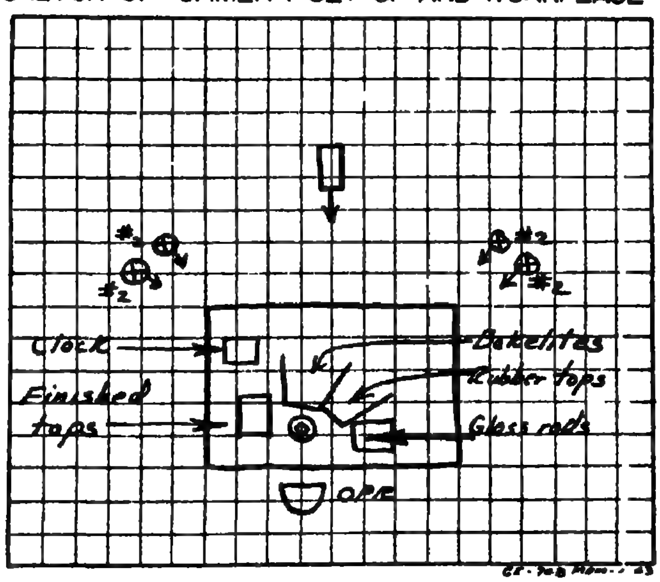
Light ⊕#

Camera

Window

Area of light reading

SKETCH OF CAMERA SET UP AND WORKPLACE



From Mundel, *Motion and Time Study: Principles and Practice*, p. 242.

FIG. 5.28 FILM DATA SHEET FOR FILM USED FOR FIG. 5.26.

RECORD OF FILM ANALYSIS

Film No: 3
Date filmed 2/16/43
Analysis by J Ross
Date 2/22/43

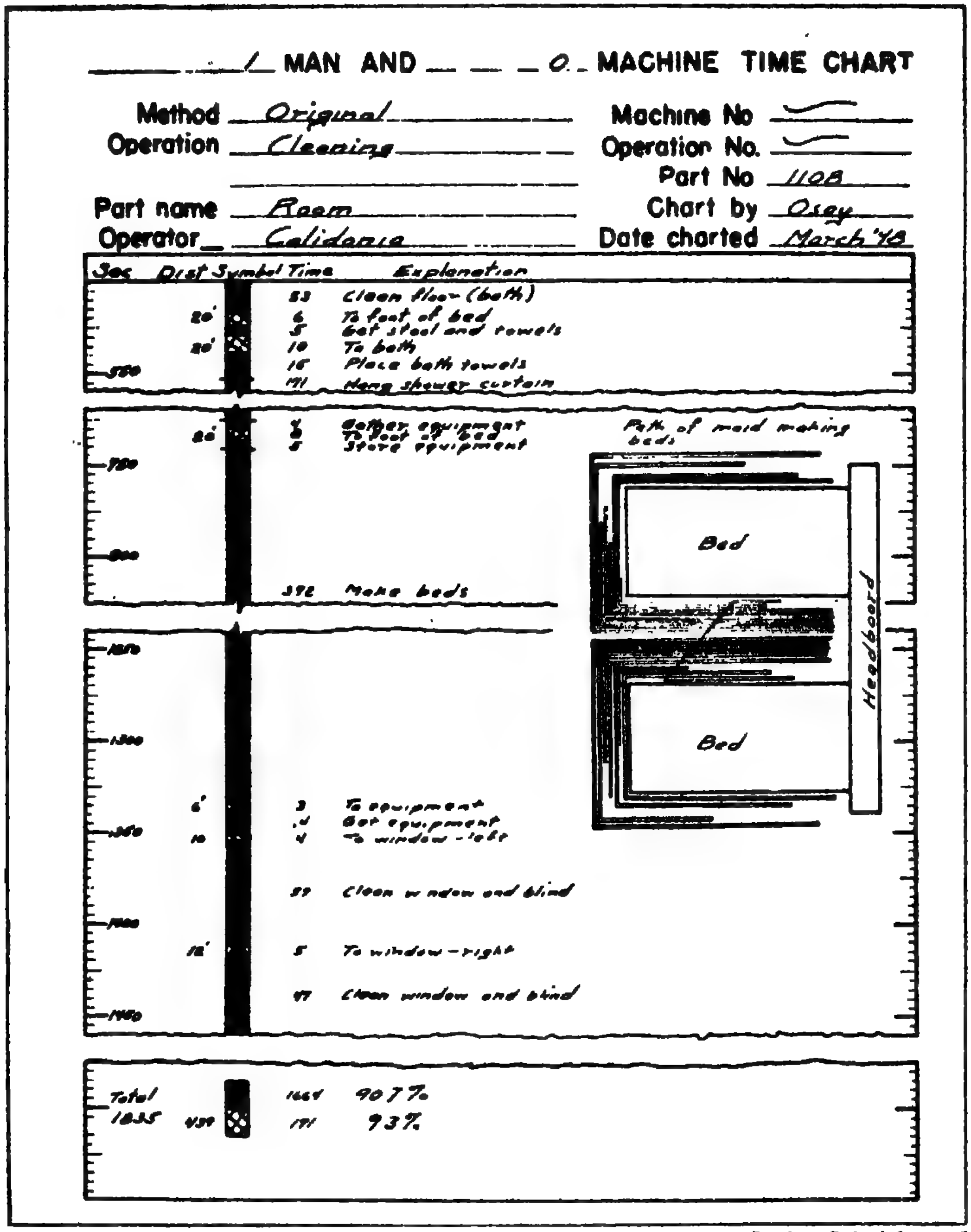
Operation Assemble
Operator Armstrong-157
Part name Bottle dropper top
Part No. 27

1 Sheet of 1
Dept. Tops-92

Clock reading	Subtracted time	Therblig symbol	Left hand description	Clock reading	Subtracted time	Therblig symbol	Right hand description	Clock reading	Subtracted time	Notes
116	8	TL	Finished part to tray	116	20	TE,UD	To rubber tops			
124	2	RL	Dropper top into tray	136	10	G	Rubber top			
126	16	TE	To bakelite caps	146	12	TL	To work area			
142	8	G	Bakelite cap	158	8	P	To bakelite			
150	4	TL	To work area	166	6	A	" "			
154	2	P	For assembling	172	2	RL	Rubber top			
156	18	H	" "	174	4	TE	To top end of rubber			
174	2	P	For RH to grasp rubber	178	2	G	" " " "			
176	14	H	" " " pull "	180	8	A	Pull rubber thru			
190	4	P	To receive glass	188	2	RL	Rubber			
194	32	H	" " "	190	6	TE	To glass rods			
226	X	TL	Finished part to tray	196	8	G	Glass rod			
116	110			204	8	TL	" " to cap			
110 ✓	OK			212	2	P	" " " "			
				214	10	A	" " " "			
				224	2	RL	" "			
				226	X	TE	To rubber tops			
				116	110					
				110 ✓	OK					

From Mundel, *Motion and Time Study: Principles and Practice*, p. 243

FIG. 5.29 FILM ANALYSIS, WITH THERBLIGS OF FILM REFERRED TO IN FIG. 5.28.



From Mundel, *Motion and Time Study: Principles and Practice*, p. 259.

FIG. 5.30 SECTIONS OF CHART SHOWING ORIGINAL METHOD OF MAID CLEANING HOTEL ROOM.

factors involved, the analyst selects the class of change or the possibility that appears most feasible. Several persons may participate in this step.

b. On the basis of the above decision and the nature of the job, the analyst selects an appropriate analysis technique from those listed in Table 5.1.

4. What then:

The analyst is now ready for Step B (Analysis) of the logical approach. Although the trained analyst may not draw up a formal possibility guide, his thinking should follow its pattern. Experience suggests, however, that the formal approach is usually much more productive than the informal approach.

3.9.2 For product analysis techniques. The procedures for using two different techniques are given.

3.9.2.1 Process chart—product analysis.

1. Uses:
   a. Provides a last check prior to a Class 1 or 2 change. (See Art. 3.3A.)
   b. Supplies information leading to a Class 3, 4, or 5 change.
   c. When planning for the manufacture of a product or the making of a plant layout.
2. How made:
   a. A form may be used, or a blank sheet of paper may be substituted.
   b. If possible, actually observe the process. If the item is not in process, or if direct observation is inconvenient, use a scale floor plan. Actual observation is more desirable, since discrepancies often exist between the supposed process and the actual process.
   c. Pick a convenient starting place for the analysis.
   d. Classify the first step according to the categories listed in Table 5.2.
   e. On the first line of the chart, enter the proper symbol and description. If the step is a movement, pace off the distance or measure it by some other means. In the quantity column, always show the amount handled as a unit on that step; if the step is a storage, indicate the usual maximum quantity. If a time measurement is desired for the step, use an ordinary watch or a stop watch, or consult the file of standard times if it is available.
   f. On the second line, enter the proper symbol for the second step, and so on.
   g. Make a separate entry every time the item moves from one workplace to another, waits, is inspected, or is worked on. However, movements that occur at a given workplace are not usually noted separately.
3. How used:

   Each step of the process is checked against the questions in the check list being used.
4. What then:

   A process chart—product analysis is drawn for a resulting suggested improved method in order to permit a final check and to provide a means of describing the proposed new method.

3.9.2.2 Procedure analysis chart.

1. General Goal. (Follow A, B, or C as applicable.)
   A. If problem is design of a new procedure and/or form(s):
      1. Define purpose.
      2. Determine what organizational segments will be affected.
      3. Determine what personnel will be affected.
      4. Determine relationship to existing procedures and forms.
      5. Determine applicable regulations.
   B. If problem is unspecified, and if the problem area must be examined before the specific problem can be defined:
      1. To analyze problem from

viewpoint of forms and form load, use functional forms analysis chart (Art. 3.5.1.5).
   a. Designate all forms duplicating one function for detailed study.
2. To analyze problem from viewpoint of personnel and work load, use work activity analysis (Art. 3.5.1.2).
   a. Supply personnel concerned with ruled sheets divided into three columns: Time, Activity, Remarks.
   b. Request personnel to maintain log of their activity for adequate period.
   c. Explain purpose in detail and assist in preparing standard terms for describing major activities to facilitate later summarizing.
   d. Answer questions.
   e. Assist and supervise collection of data.
   f. Determine most pressing needs from above data and designate activities that need detailed study. (*Note:* A record may also be made of overloaded equipment.)

C. If problem is the improvement of a specific procedure and/or form(s):
   1. Determine nature of specific problem and decide whether problem is:
      a. Redesigning a procedure.
      b. Redesigning a form.

2. Specific Goal (Selecting an objective or guide. If problem concerns the initial design of a procedure or form, select mos. desirable objectives to optimize; note that it is difficult to optimize all factors at once.)
   A. Consider the following list of possible objectives:
      1. Fewer people.
      2. Fewer steps (in procedure or in using form).
      3. Less time on a step or steps.
      4. Less time in production (for all-over procedure to be completed).
      5. Less space.
      6. Less time spent in using critical skills or critical personnel.
      7. Less time spent on critical equipment.
      8. Increased quality (accuracy).
      9. Less cost.
      10. Less skill needed for various steps.
      11. Better control.
      12. Other (state).
   B. Using experience, direction, or a balancing of needs to guide you, select one or more as an objective.
   C. Check the objective selected with your superior or with affected personnel.

3 Preliminary Analysis.
   A. Determine roughly the degree of change that is desirable or feasible.
      1. Consider the following factors:
         a. How great is the actual or expected volume of the activity?
         b. How long will it last?
         c. How much time, per unit, is spent on the job?
         d. How much time is available to work up a change?
         e. How much is already invested in equipment for the job?
         f. How much analysis time will be required?
         g. How much time would be lost in a change?
         h. How pressing is the need?
         i. How much retraining would be required?
         j. What is the possible saving?
         k. What personalities are involved?
         l. Does policy allow a change?

m. Is any aspect beyond control; if it is, who must be consulted?

B. Evaluate each of the above factors as well as possible at this initial stage.

C. On the basis of this evaluation, set rough limits for the analysis activity.

4. Follow either A or B below, as applicable.

A. For the analysis of an existing procedure:

1. Using symbols of Table 5.3, and a form such as Fig. 5.14, make charts of all the forms being used.

a. Discuss each form with individuals concerned. Follow a copy of form from inception of use to final disposal. Place remarks made by individuals on your notes if important.

b. Record separable activities of each form with symbols and explanations.

c. Check against standard instructions, if available.

2. Draw procedure chart, columnating by forms, persons, or offices as appears most desirable. Integrate material collected at Step 1 above so that a horizontal line drawn across chart at any point passes through items that are happening at the same time.

B. For the design of a procedure:

1. Using the symbols of Table 5.3 and a blank chart, lay out procedure. As you proceed, take into consideration the items of the check list and the applicable items listed under Step 1 (General goal).

2. Treat as you would an existing procedure and attempt to make improvements.

5. Check against the appropriate check list.

6. Consult trade catalogs for alternatives and suggestions.

7. Discuss suggestions from 5 and 6 with affected personnel.

8. Draw up proposal, using procedure analysis chart.

9. Consult with supervisor for interim advice and direction.

10. Treat your proposal with the items from Steps 5, 6, and 7 as if it were an original analysis.

11. Discuss final result with all concerned as a "proposal." Work up through the affected segment, adjusting proposal if necessary. Consult with supervisors and workers to obtain participation rather than just acquiescence.

12. Submit proposal through channels.

13. Await authorization to proceed.

3.9.3 For man analysis techniques. The uses of the major techniques are outlined below. A more detailed procedure such as that given in Art. 3.9.2.2 could be evolved for each technique.

3.9.3.1 Process chart—man analysis.

1. Uses:

a. Supplies information leading to a Class 1 or 2 change in a job that requires the worker to move from place to place. (*Note:* Higher classes of change are occasionally suggested by an analysis of this type and should not be overlooked.)

2. How made:

a. Either a form such as appears in Fig. 5.11 or 5.15 or a blank sheet of paper may be used.

b. The chart may begin at any point in a cycle of work (see Art. 3.8.2.2) considering a cycle as the complete set of steps necessary to bring a unit of the goods to the degree of completion typical of the work. However, it is usually most convenient to begin with the first step connected with a particular unit and end on the last step before the next similar unit is worked on or a new routine is started.

c. The first step in the cycle should be carefully classified according to the categories in Table 5.4.

The symbol, explanation, and, if the step is movement, the distance should be entered on the first line of the chart. The explanation should be as succinct as possible. The distance may be paced, estimated, measured on the actual floor plan, or scaled from a drawing.

d. If a time measurement for the step is desired, use an ordinary watch or stop watch.
e. Information for subsequent steps should be entered on subsequent lines, in such a way that the symbols, explanations, and so forth form separate columns for easy reading.
f. An entry should be made for every separable phase of the work, for every time the worker moves from one place to another, and for every time the worker works at a workplace. When two distinctly separate activities follow each other at a workplace without an intervening movement, two operation symbols, one after the other, may be entered.
g. The steps should represent the activities of the worker—i.e., what he does to the product, and where he goes—rather than what happens to the product.
h. If the job has several subcycles occurring at different frequencies, each subcycle should be charted separately, and its frequency of occurrence should be noted.
i. If the job has a variable cycle, classify and handle as indicated:
   A. Variations caused by operator habit. Chart several versions to insure adequate data.
   B. Variations inherent in job and each different. Plot general pattern, marking parts that are constant and parts that vary from cycle to cycle.
   C. No pattern or cycle. Plot a selected period of work as it occurs.
j. A man flow diagram (see Art. 3.5.2.2) is often a useful adjunct to the process chart—man analysis.

3. How used:
   a. Each step of the process is checked against the questions in the check list being used.
4. What then:
   a. A process chart—man analysis is drawn for a resulting suggested improved method in order to permit a final check and to provide a means of describing the proposed new method.

3.9.3.2 Operation chart.

1. Use:
   a. Supplies information leading to a Class 1 or 2 change in a job that takes place at one location and in which the operator rather than a machine controls the flow of work.
2. How made:
   a. Operation charts are best prepared by actually observing the worker, although they may be prepared from a proposal for a method.
   b. Either a form such as that in Fig. 5.18 or a blank sheet of paper may be used.
   c. Although the chart may begin at any point in the work cycle, it is usually most convenient to begin with the hand that makes the first movement attributable to a unit of product.
   d. The first and last cycle of a work period may be different from the other cycles. It is usually desirable to chart the most typical cycle.
   e. The first step of the hand that begins the cycle should be classified according to the categories in Table 5.5. An entry should then be made on the first line, as in Fig. 5.18. The symbols are usually drawn freehand.
   f. All the steps of this hand should then be classified and plotted in order. Several cycles may have to be observed before this infor-

mation can be recorded in complete form.

g. The steps of the other hand should then be plotted. Each step for this hand must be recorded opposite the step of the other hand during which it occurs.

h. Since the chart may become congested and confusing when all this information is coordinated, it is frequently necessary to redraw it in order to make it easily legible, as in Fig. 5.18. However, since the chart is mainly an aid to understanding, excess draftsmanship is a waste of time and should be avoided.

i. A summary should be placed at the bottom of the chart.

j. A sketch of the workplace is often a useful adjunct.

3. How used:
   a. Each step of the operation is checked against the questions in the check list for operation charts (see Table 5.16).
   b. The general principles listed at the top of the check list should serve as objectives.
4. What then:
   a. An operation chart is drawn for the resulting suggested method in order to permit a final check and to provide a means of describing the proposed new method.
   b. A revised sketch of the workplace is usually drawn, and drawings of the necessary tools, jigs, fixtures, bins, and so forth are prepared.

3.9.3.3 Multiple-activity charts. For convenience, all procedures for using man and machine charts have been combined into one group and all procedures for multi-man charts into another.

Man and machine charts.

1. Uses:
   a. Improve utilization of man or machine and improve integration of the two on jobs where the man works with one or more machines and where the work of the machine is a controlling factor.
   b. Aid in selecting a man and machine work pattern appropriate to production requirements and cost conditions.
   c. In the simpler forms, aid in determining where more detailed analysis techniques may be usefully applied.
2. How made:
   a. Man and machine operation charts are constructed as follows:
      (1) A right- and left-hand operation chart is constructed, as summarized in Art. 3.9.3.2.
      (2) The machine is then charted by the use of a procedure similar to that used for placing the second hand on right- and left-hand operation charts, with the machine information being placed on the chart as shown in Fig. 5.21. Usually, only two symbols are used for the machine: the suboperation symbol when the machine is working and the delay symbol when it is idle.
      (3) A summary is placed at the bottom of the chart.
   b. Man and machine operation time charts are constructed as follows:
      (1) A man and machine operation chart is drawn.
      (2) Sample time values are obtained for each step, by means of a watch, film records, or standard time tables.
      (3) A second chart is drawn either on the form shown in Fig. 5.22 or on a sheet of graph or cross-section paper, using the conventions established in Table 5.6. The length of the shading of the bar for each step on the chart is made proportional

to the time involved. A time scale should be devised so that each line of the chart will represent the same time value and the chart will be of convenient size.

(4) A summary may be placed at the bottom of the chart, although the length of the chart is itself a rough summary, giving the total time for the operation.

c. Man and machine process time charts are constructed as follows:

(1) A process chart—man analysis is constructed, as summarized in Art. 3.9.3.1. The information is usually confined to the left half of the chart, and the right half is left blank.

(2) The machines used are charted on the same sheet, as with man and machine operation charts, and the steps of the machines are keyed into the process chart.

(3) By use of a watch, stop watch, camera, or table of time values, the time is determined for each item on the chart.

(4) By use of a form similar to that in Fig. 5.23 or a sheet of graph or cross-section paper, the chart is redrawn. The conventions of Table 5.7 are used, and the length of each item is made proportional to the time involved. A convenient scale should be chosen and a time value assigned to each line of the chart so that the chart is of a convenient size. The scale should be the same throughout the chart.

(5) A summary may be placed at the bottom of the chart, although the length of the chart is itself a rough summary, giving the total operation time.

3. How used:

Each step of the method analyzed should be checked against the questions included in suitable check lists.

With the more complex tasks, the desired type of solution should be stated as a criterion for selection.

The time chart may be used to locate sections of the task that need more intensive study.

4. What then:

A chart of the proposed method is either constructed or selected from the available solutions for the subsequent steps; or more detailed analyses, for further study, may be made of sections of the task.

Multi-man charts.

1. Uses:
   a. Arranging crew work for the best balance.
   b. Estimating the effect of varying the size of the crews.
   c. As a basis for instructing the crew.
   d. Locating sections of the task where a detailed right- and left-hand analysis is needed to develop an improvement.
2. How made:
   a. A process chart—man analysis is constructed for one of the crew members, with the information confined to one side of the chart. The classification of steps, symbols, and procedure is the same as with process charts—man analysis.
   b. The other crew members are charted, one at a time, on the same sheet. Symbols that indicate simultaneous activities should be entered on the same line.
   c. Next, machine or machines are analyzed in a similar manner on the same chart.
   d. The time is obtained for each item on the chart. If watches are used, the times will be collected from several cycles, hence some adjustment may be necessary to obtain comparable values. If

films are used, the same cycle of work can be used for all entries.

e. By the use of a form similar to Fig. 5.25 or a sheet of graph or cross-section paper, the information obtained in the previous steps is recharted, using the conventions of Table 5.7 and a convenient time scale.

f. A summary may be placed at the bottom of the chart, although the length of the chart is itself a rough summary, giving the total cycle time.

3. How used:

Each step of the operation is checked against a suitable check list. The general principles listed at the top of the check list should serve as objectives.

4. What then:

A new multi-man chart is drawn for the resulting suggested method in order to permit a final check and to provide a means of describing the proposed new method. If effects of variations in crew size are being examined, several alternative charts may be drawn.

3.9.3.4 Micromotion study. Summary procedures are given for fine and gross types of analysis.

Simo charts.

1. Uses:
   a. Primarily for short-cycle, repetitive jobs.
   b. For jobs involving high-order skills.
   c. For jobs representing a series where the changes involved may affect several jobs similarly. *Note:* The general outline offered here can be used for any of the previously described graphic man analysis techniques.
2. How made:
   a. A film is made of the operation, with a timing device in the field of view.
   b. If the film is analyzed with the therblig breakdown, it is desirable to use the following steps in connection with a form for film analysis such as that shown in Fig. 5.29 or a sheet of ruled columnar paper.
      (1) To facilitate future reference, the data at the top of the sheet are obtained from the micromotion study film data sheet.
      (2) The entire film is viewed, and a typical whole cycle is selected. A cycle is defined as the complete series of motions required to bring a unit of product to the degree of completion characteristic of the operation. As with the previous techniques, it is usually most convenient to select the cycle as starting with the first motion connected with the production of a unit and ending when the same motion is repeated with the next unit.
      (3) The activities of one body member, usually the busiest, are recorded by noting, on the first line, the beginning time (the clock or counter reading for the first frame or picture in which the therblig appears), for the first therblig of the cycle for that body member, the therblig letter symbol, and the explanation. Then the projector is turned till the next therblig appears; appropriate information is entered on the second line; and so on. The explanation should assume that the therblig is the verb and should tell what and where the action is. The actual therblig times may be obtained later by successive subtractions. It is customary practice to follow each body member through the entire cycle, and then to repeat the cycle for as many times as there are body members being studied.

For therbligs such as RL, which may take place entirely between two successive pictures and not appear on the film at all, the time interval between the two pictures is usually arbitrarily assigned. At the normal speed of 16 frames, the interval will be approximately 0.001 minute. On the form given in Fig. 5.29 space is provided for the two hands; the column headed "Notes" is for the analysis of any other body member, such as feet, eyes, and so forth. This is the most common type of analysis. Special forms may be designed for more complex analyses.

c. A simo chart is drawn to assist in examining the interrelationships of the body members concerned.

3. How used:

Each step of the operation is checked against a suitable check list. The general principles listed at the head of the check list should serve as objectives.

4. What then:

A new simo chart is synthesized for the resulting suggested method in order to permit a final check and to provide a means of describing the proposed new method.

Memomotion study.

Since the application of this technique varies greatly with the nature of the objective and the subject, a complete case is given as a guide for developing a procedure.

1. Uses:
   a. Long cycles.
   b. Irregular cycles.
   c. Crew activities.
   d. Long-period studies.
2 Sample case: *Three-man crew running heavy castings through a "Rotoblast."*

A possibility guide had indicated that a Class 1 or 2 change was desirable, and a study of the process chart—product analysis suggested that the operation, shot-blast casting, was necessary. This completed Step A of the logical approach, *Aim.* For convenience and accuracy, Step B, *Analysis* was performed with a memomotion camera. Since sufficient light from the building monitor penetrated even the murky interior of the foundry, there was no need for supplementary lighting. The crew members, aware that they were being photographed, were filmed at work, and an analysis was made of the film in order to obtain data with which to construct a multi-man and machine process time chart.

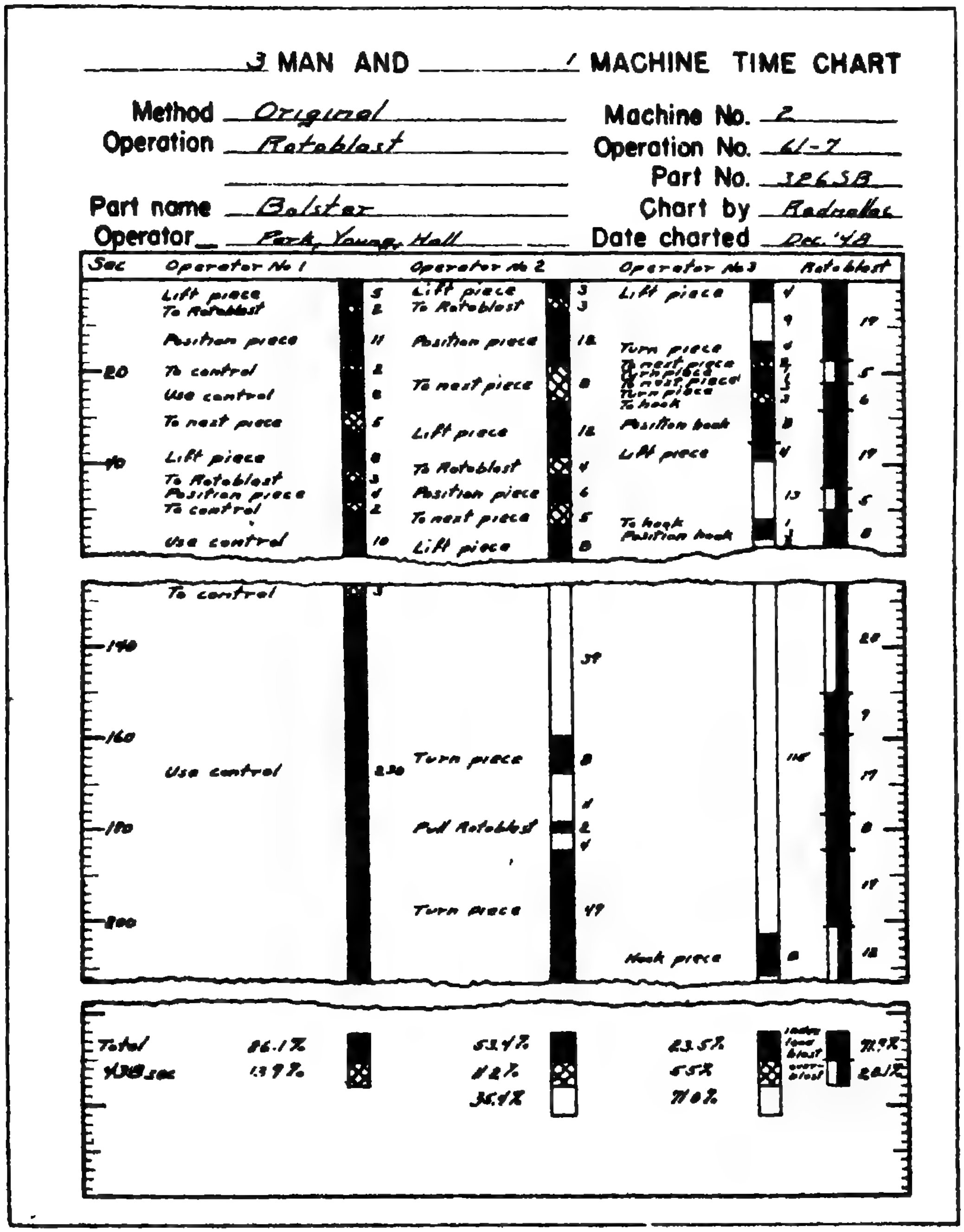
The analysis was made with a projector equipped with a frame-counter. A typical cycle was selected. Since the selected cycle was 439 seconds long (7.3 minutes), and there are 40 frames per foot on 16 mm. film, the selected section was only 11 feet long. At normal speeds, the cycle would have occupied almost 200 feet of film. (The analysis time saved by using the memomotion film should be obvious.) The selected cycle was identified for future examination by placing an ink spot on the beginning frame. The beginning counter reading, a process chart—man analysis symbol, and a description for one operator were entered on the first line of a ruled sheet. The projector was indexed until the first frame showing a new activity appeared, and the appropriate information was entered on the second line. This procedure continued until all the activities of the operator had been detailed for the whole cycle. The film was then returned to the starting point and the second operator's activities were analyzed.

In this case, the film was studied four times, once for each of three workers and once for the machine. Sections of the chart made for the original method are shown in Fig. 5.31. The sections on the chart marked "overblast" could not be determined from the film; they were worked out with the aid of experimental data on the minimum required shot-blasting time. In drawing the chart, these

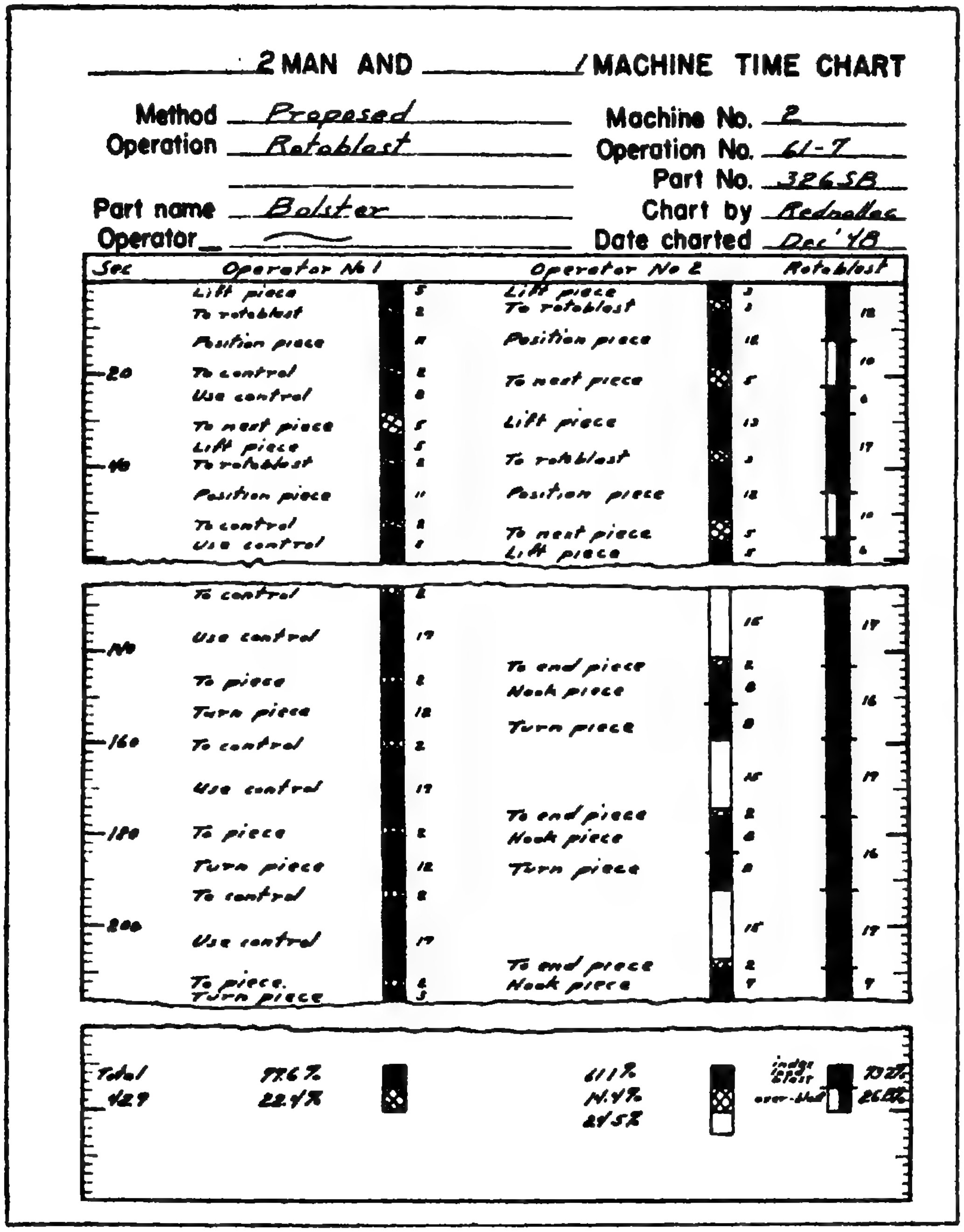
experimental data were used to denote the unnecessary blasting, which was labeled "overblast."

Although the chart could have been made without film, the use of film assured data on all men from the same cycle, was quicker, gave better accuracy, and provided a record to use in checking the analysis. Moreover, memomotion films possess a unique feature. When they are projected at normal speed, they exaggerate the movements made and call them to the analyst's attention for modification and improvement. They also permit a long period of activity to be reviewed in a short time. Since an hour's activity can be projected in four minutes, a "bird's-eye" view of a task is presented that often aids in suggesting innovations. Memomotion films are also valuable in

FIG. **5.31** SECTIONS OF CHART SHOWING ORIGINAL METHOD OF "ROTOBLAST."



From Mundel, *Motion and Time Study: Principles and Practice*, p. 255.



From Mundel, *Motion and Time Study: Principles and Practice*, p. 256.

FIG. **5.32** SECTIONS OF CHART SHOWING PROPOSED METHOD OF "ROTOBLAST."

discussions with foremen and workers, since only a short time away from the job is needed to review a lengthy period of work.

The proper multi-man check list was used on this foundry chart and the new method, parts of which are shown in Fig. 5.32, resulted. The improved method saved 35 per cent of the man-minutes of work per unit and increased hourly production by 2 per cent. It did not require the crew to work faster, but it did make for a better distribution of the work and provided a more effective work pattern.

The memomotion film was also used in the discussions that preceded the installation of the new method.

4. WORK SIMPLIFICATION

To some, work simplification is synonymous with motion study. To others, it is a proprietary, simplified version of motion study that an individual can apply to his own work. Perhaps it should be thought of more generally, as a motion-study approach suitable to the educational level of the foreman or worker and usually (but not necessarily) involving the use of only the simpler, pencil-and-paper techniques. Suitable parts of Art. 3 should be consulted.

5. TIME STUDY

5.1 DEFINITION

Time study is the appraisal, in terms of time, of the value of work involving human effort. It produces a time standard for the performance of a series of acts by a man or group of men. To avoid chaos, a standard should be carefully defined so that consistent, reliable measurements may be made. A sample, specific definition of a standard is as follows: The standard time for a job will be 130/100 of the amount of time necessary to accomplish a unit of work, using a given method, under given conditions, by a worker who possesses sufficient skill to do the job properly, who is as physically fit for the job after adjustment to it as the average person who can be expected to be put on the job, and who works at the maximum pace that can be maintained on such a job, day after day, without harmful physical effects.* The term "time study" may also be used as synonymous with the term "work measurement."

5.2 USES

Standard times may be used for the following purposes:

A. To set schedules.
B. To determine supervisory objectives.
C. To furnish a basis of comparison for determining operating effectiveness.
D. To set labor standards for "satisfactory" performance.
E. To determine the number of machines a person may run.
F. To balance the work of crews or production lines.
G. To compare alternative methods.
H. To determine standard costs.
I. To determine equipment and labor requirements.
J. To determine basic times or standard data.
K. To provide a basis for setting piece prices or incentive wages.

5.3 TECHNIQUES

In order to set up an adequate, reliable time standard, the following items must be specified: the internal content of the task (the contribution required of the individual), the unit of output involved, the type of individual for whom the standard is determined, and the degree of exertion required of the individual. Further, it should be obvious, that for widespread use, a set of standards should be consistent with each other in respect to difficulty of attainment.

5.3.1 List. Available techniques may be divided into three major groups, as follows:

A. Stop-watch (or camera) time study. First, an actual performance is studied and analyzed. Then the data obtained are synthesized into a standard. (The result is sometimes called an "engineered standard of performance.")
B. Synthesized standards. Data obtained from previous time studies, giving standards for parts of jobs, may be resynthesized into a standard for a job, in its totality, different from those previously studied. (Standards set in this

* This limit is usually based on sociological acceptance rather than on physiological limits. The modern worker expects to leave work with sufficient energy to engage in leisure-time activities.

manner are also referred to as "engineered.")

C. Statistical standards. Data obtained from a considerable number of people performing tasks over a considerable period of time are used on some arbitrary basis. As will be seen, such "standards," although useful, lack many of the requisites of true standards.

5.4 STEPS IN THE DETERMINATION OF A STANDARD

Each of the three basic groups contain numerous variants in method. However, the general steps remain the same; only the details vary.

5.4.1 Stop-watch (or camera) time study. The procedure usually involves the following five steps:

A. Defining the standard of measurement.
B. Recording the standard method and identifying the unit of work.
C. Observing the time taken by an actual worker.
D. Rating or relating performance to standard.
E. Applying allowances.

5.4.1.1 Defining the standard of measurement. This need be done only once for all the standards in a plant. (See Art. 5.1 for an illustration.)

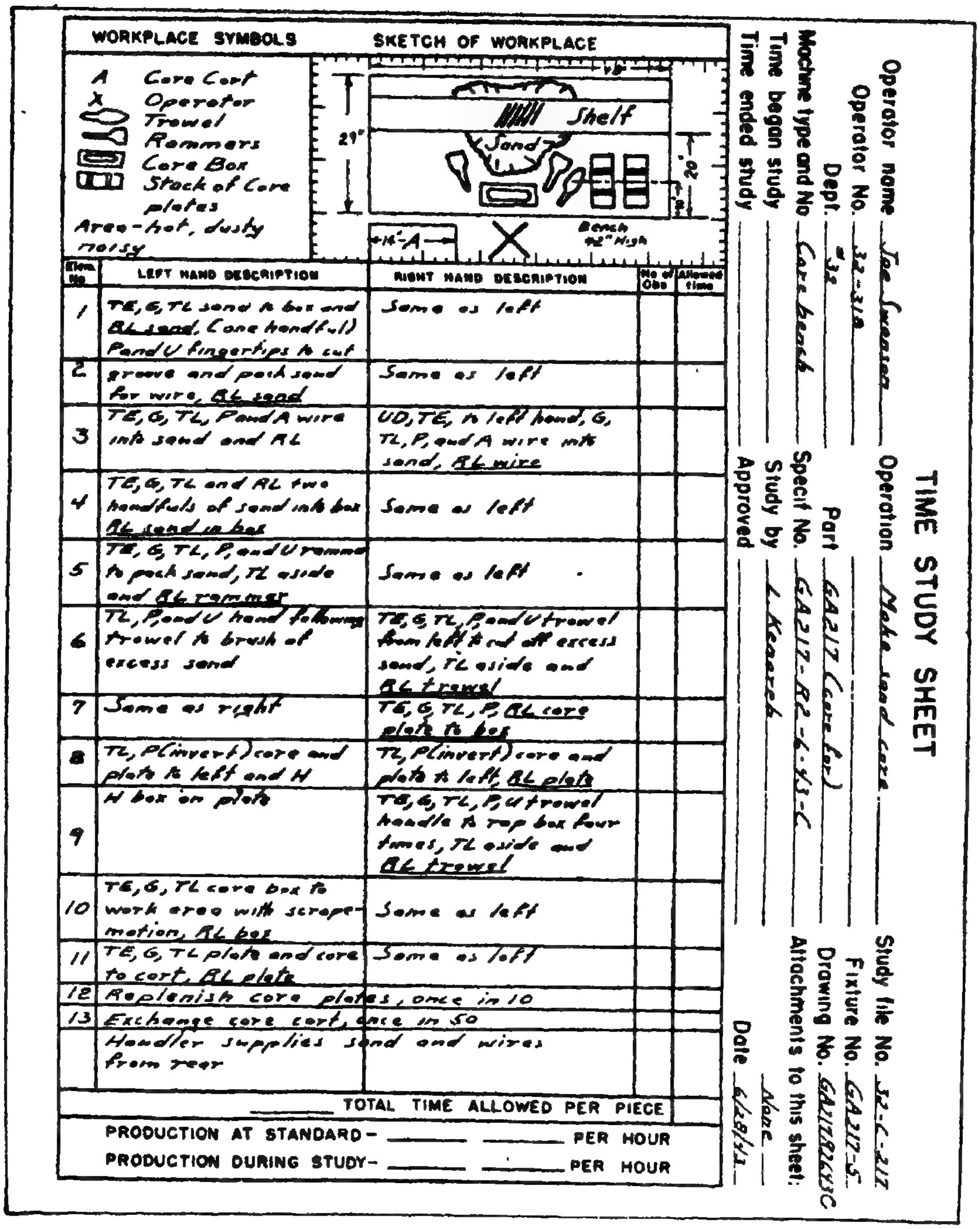
5.4.1.2 Recording the standard method and identifying the unit of work. The essential criteria for the identification are:

A. Could the job be reproduced from it?
B. Does it contain everything the worker has to do?
C. Is the unit of work such as to allow convenient determination of production on the job?

The following items are usually included:

1. The department in which the job is performed.
2. Job number.
3. Product, material specifications, and identification as related to the operation.
4. Workplace layout and dimensions.
5. Description of equipment and its condition, if abnormal.
6. Tool descriptions.
7. Feeds and speeds of machines, welding currents used, and so forth.
8. Surrounding environmental conditions.
9. Services related to machine and tool maintenance, delivery, and material-handling rendered to, or required of, the worker.
10. The unit of production to be counted.
11. A description of the manual details of the job. These are usually broken down into so-called "elements," in accordance with the following criteria:
    A. Easily detected and definite end points.
    B. As small as is convenient to time.
    C. As unified as possible.
    D. Hand time separated from machine time.
    E. Constant elements separated from variables (as related to several jobs).
    F. Regular and irregular items separated.

The terminology used in the description of the elements varies with the nature of the job. For heavy work involving movement from place to place, a description of the activities of the person as a whole is most suitable. For heavy work with crews, the activities of the individual crew members, and their coordination, must be indicated. For heavy and moderately heavy work done mainly at one place, the activity of the individual as a whole is sufficient, unless the coordination of the worker's body members is a critical factor, in which case the activities of each body member should be detailed and the coordination indicated. This latter procedure is also preferable for light work. Therblig terminology is also useful in descriptions, particularly for small handwork. Of course, if therblig time studies are shown to men who are unfamiliar with the terminology, they will



TIME STUDY SHEET

Operator name Joe Swenson
Operator No. 32-318
Dept. #32
Machine type and No Core bench
Time began study
Time ended study
Operation Make sand core
Part GA217 (core box)
Specif No. GA217-R2-6-43-C
Study by L Kearch
Approved
Study file No. 32-C-217
Fixture No. GA217-5
Drawing No. GA217R2C43C
Attachments to this sheet: None
Date 6/28/43

WORKPLACE SYMBOLS

A Core Cart
X Operator
Trowel
Rammers
Core Box
Stack of Core plates
Area-hot, dusty noisy

SKETCH OF WORKPLACE

Elem. No.	LEFT HAND DESCRIPTION	RIGHT HAND DESCRIPTION	No. of Obs.	Allowed time
1	TE, G, TL sand to box and RL sand. Cone handful) P and U fingertips to cut	Same as left		
2	groove and pack sand for wire, RL sand	Same as left		
3	TE, G, TL, P and A wire into sand and RL	UD, TE, to left hand, G, TL, P, and A wire into sand, RL wire		
4	TE, G, TL and RL two handfuls of sand into box RL sand in box	Same as left		
5	TE, G, TL, P, and U rammer to pack sand, TL aside and RL rammer	Same as left		
6	TL, P and U hand following trowel to brush of excess sand	TE, G, TL, P and U trowel from left to cut off excess sand, TL aside and RL trowel		
7	Same as right	TE, G, TL, P, RL core plate to box		
8	TL, P (invert) core and plate to left and H	TL, P (invert) core and plate to left, RL plate		
9	H box on plate	TE, G, TL, P, U trowel handle to rap box four times, TL aside and RL trowel		
10	TE, G, TL core box to work area with scrape-motion, RL box	Same as left		
11	TE, G, TL plate and core to cart, RL plate	Same as left		
12	Replenish core plates, once in 10			
13	Exchange core cart, once in 50			
	Handler supplies sand and wires from rear			

_______ TOTAL TIME ALLOWED PER PIECE

PRODUCTION AT STANDARD – _______ _______ PER HOUR

PRODUCTION DURING STUDY – _______ _______ PER HOUR

From Mundel, *Motion and Time Study: Principles and Practice*, p. 283.

FIG. **5.33** FRONT OF TIME STUDY SHEET WITH METHOD DESCRIPTION IN TERMS OF THERBLIGS FOR SAND-CORE MOLDING.

be unintelligible and may arouse mistrust. However, since more and more plants are undertaking training programs in motion and time study for foremen and supervisors, therbligs are constantly coming into more common use. In any event, they furnish a shorthand for record-taking, and may be expanded for instructional use later on.

In some cases, a single time-study

FIG. **5.34** PART OF METHOD DESCRIPTION FOR TWO-MAN BURR ROLL.

STANDARD METHOD FOR BURR ROLL - "SUPER STRIP", 2 MAN CREW — 1 sheet of 2
150 lb. COIL — 3/4" WIDE — 4 WIRE TIES

Element No.	Operator	Element No.	Helper
1	Stop machine and walk from control lever to coiler	1	Pick up 4 pieces of wire from holder, place 4 pieces of wire 90 degrees apart on top of finished coil on skid and step to coiler
2	Inspect last end of coil, pick up snips from machine framework, cut off last end of coil and lay end and snips on machine framework	2	Remove handwheel and front plate, pulls coil a little away from back plate and slip on coil clamp
3	Walk from coiler to spare reel		
4	Index swivel reel, pick up end of coil on spare reel and feed thru Burr Roller to feed rolls		
5	Walk from feed rolls to coiler		
5a	With helper lift coil off coiler and place on skid	3	With operator lift coil off coiler and place on skid
6	Walk from coil on skid to control lever	4	Remove core from coil on skid and place on coiler
7	Start machine and feed end of coil thru feed rolls and past coiler and stop machine	5	Delay
8	Walk to coiler		
9	Inspect first end of coil, pick up snips from machine framework, cut off first end of coil and lay end and snips on machine framework		
10	Walk from coiler to control lever	6	Rethread coiler, take up slack and replace front plate and handwheel
11	Delay		
12	Start machine and walk from control lever to spare reel	7	Step to coiled strip on skid
13	Unscrew reel handwheel from reel shaft and lay on floor out of way	8	Pick up one end of wire under finished coil on skid, make 1 wire tie around coil by hand, twists wire tight around coil with pliers, and bends ends flat on coil
14	Pull reel front plate from reel shaft, roll to support and lean front plate against support	9	Repeat No. 8
15	Pick up hook, pull coil about 8" off pile on skid and lay hook down	10	Repeat No. 8
		11	Repeat No. 8

From Mundel, *Motion and Time Study: Principles and Practice*, p. 286.

HISTORY DETAIL

Machine Data

	ELEMENT No				
	1	2	3	4	5
Average Diameter of Part					
Spindle Speeds					
Cutting Speeds, Feet Per Min.					
Feed Per Minute					
Feed Per Revolution					

Type of Machine ________

Type of Chuck ________

Material Machined ________

Cutting Tools: Carbon ☐ High Speed ☐ T. C. C. ☐

Classification or Type of Tools ________

Moulding Data

Type of Machine ________

Metal Used ________

Type of Flask ________

Size of Flask: Length ____ Width ____ Height ____

Type of Pattern ________

Number of Pieces on Gate ________

Number of Cores ________

Dry Cores ____ Green Cores ____

Number of Loose Inserts on Pattern ________

Number of Riser Blocks ________

Number of Men: Molders ____ Helpers ____

Sketch:

Remarks: ________

FIG. **5.35** A TIME STUDY FORM ADAPTED FOR MACHINE OPERATIONS.

sheet is sufficient for recording the standard practice. In other cases, it is necessary to attach drawings of the tools and other equipment. In still others, the written standard practice may run to several pages. No one form has yet been devised that will handle the problems of all plants satisfactorily. A sample description for a bench job is shown in Fig. 5.33, and part of the description for a two-man job is shown in Fig. 5.34. Still another time-study form is shown in Fig. 5.35.

5.4.1.3 Observing the time taken by an actual worker. Six different methods of recording observed times are in common use. Four of these involve the use of a stop watch; one, the use of a motion-picture camera; and one, the use of a special time-study machine. Under certain conditions, a sound recorder may be used advantageously.

Continuous timing. The watch runs continuously throughout the study. It is started at the beginning of the first element of the first cycle being timed, and is not stopped until the study has been completed. At the end of each element, the time is recorded. The individual element times are obtained by successive subtractions after the study has been completed.

Repetitive (or snap-back) timing. The watch is started at the beginning of the first element of the first cycle being timed, and is simultaneousy read and snapped back to zero at the completion of this, and each subsequent, element. This procedure allows the element times to be entered directly on the time-study sheet without the need for subtractions. Consistent over- and under-reading of the watch will cause errors that do not arise in the continuous method. Also, considerable manipulation of the watch is required. Many labor groups look upon the repetitive method as highly liable to error. With extremely short elements, any errors that occur may represent large percentages of the elements. Some time-study men use an additional watch to accumulate the total time as a check on these errors. However, in competent hands, the snap-back method can be used successfully.

Continuous accumulative timing. Two stop watches are mounted on a special holder with a mechanical linkage between the controls of the two watches. The push buttons on this holder are so arranged that when one watch is stopped the other is started, and vice versa. The watches are used alternately, each accumulating the time for half of the elements. This method allows each watch to be read while the hand is motionless. In obtaining the actual element times, alternate recordings are subtracted successively.

Repetitive accumulative timing. The same set-up is used as in continuous accumulative timing, except that another button is provided to return the stopped watch to zero before the next element ends. Hence, actual element times may be recorded directly. This is a reasonably accurate method. However, most time-study men regard the mechanism as troublesome, and accumulative methods are not widely used.

Motion-picture camera timing. Regular speeds may be used, although memomotion speeds are more useful. Regular film-analysis techniques are used to obtain the actual data.

Time-study machines and sound recorders. A common time-study machine employs a constant-speed paper tape with finger-actuated pencil markers. Accurate time measurements can be made by depressing the markers according to a predetermined scheme, and then measuring the distance between the marks with a calibrated ruler. If the task involves communications, a sound tape recording may be made and later transcribed and interpreted on a recording oscillograph. This record may be measured, as with the time-study machine. Also, special sound cues may be recorded on the tape while an operation is being observed, and these may be timed later either with a watch or a recording oscillograph. Under certain conditions, these procedures are ideal.

Time recording forms. For recording

the time values measured with a stop watch, the form shown in Fig. 5.36 is convenient. Many variations of this form are used with equally good results. The form is often printed on the back of the form used to record standard practice, shown in Art. 5.4.1.2. It should never be used without an adequate written standard practice. On the example shown, the end point of each element after which the time is to be recorded should be written in the small description column, as an aid in timing. Space is provided on this form for recording 15 cycles of 15 elements. If more elements or cycles are to be recorded, two or more sheets may be used. If the use of two sheets is a common occurrence, a larger form should be designed and printed. For each element of each cycle, two boxes are provided in columns labeled R and T. The R column is for "readings" when continuous timing is used. The subtracted times, which are the time values for each element, are placed in the T, or "time," column. Different-colored pencils keep the R and T values separate and facilitate correct calculations later. If repetitive timing is used, the values are entered directly in the T column, or else a form with T columns only may be drawn up. It is usual practice to time enough cycles to obtain a representative sample of performance.

Representative sample of times. Some variation almost always occurs from reading to reading for any element, even if the worker is not attempting to vary his pace. This variation is caused by the following factors, among others:

1. Random variations in operator movements and pace.
2. Random variations in the positions of the parts worked with.
3. Random variations in the position of the tools used.
4. Random variations caused by slight errors in watch-reading.

For any observed pace of performance, timings of 10 cycles will tend to produce a more stable average than timings of 5 cycles; the average of 15 timings will tend to be better than that of 10, and so forth. In practice, however, two sets of 15 readings on the same element will seldom, if ever, produce an identical average, even though the pace is the same in both cases.

A reasonable limit on the number of readings is to take enough to make the chances 95 out of 100 that the observed average will be within ± 5 per cent of the true average for the element for the pace at which it was performed. Some may prefer a looser criterion of 95 chances out of 100, ± 10 per cent. These odds may be restated as 68 out of 100, ± 5 per cent.

If the time studies are to be used for establishing incentive wages, either criterion is reliable enough, since ± 5 or 10 per cent usually approximates a bargainable increment in wages. Errors of more than this magnitude are to be avoided.* (See Section 17.)

Statisticians have developed methods for determining the probable accuracy of a sample. These methods may be adapted to this time-study problem.

The applicable sampling theories involve two simple formulas, (A) and (B), which follow. Both are based on the assumption that chance or random causes are controlling the variation from reading to reading for a given element. In most cases, this is a tenable assumption.

Formula (A) gives a measure of the variability of data about its average. The variability is represented by SD, the standard deviation, which is expressed as follows:†

$$\text{SD} \quad \sqrt{\frac{\Sigma d^2}{N}} \qquad \text{(A)}$$

* William Gomberg, *A Trade Union Analysis of Time Study* (Chicago: Science Research Associates, 1948), p. 14.

† SD is used here in place of the symbols σ or s, which are used in Sections 13 and 14 for standard deviation. SD_x is used in place of σ_x. See Section 13 for a complete discussion of industrial statistical methods.

ELEMENTS		CYCLES															
		1		2		3		4		5		6		7		8	
No.	TERMINAL POINT	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T
1	RL pen into rack	03	3	59	3	13	3	72	3	34	3	89	3	45	3	03	3
2	DA filling cap	21	18	78	19	33	20	89	17	53	19	07	18	64	19	20	18
3	RL cap	41	20	96	18	52	19	10	21	72	19	27	20	84	20	39	19
4	RL clip top	56	15	10	14	69	17	3x	21	86	14	42	15	99	13	53	14
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	

		9		10		11		12		13		14		15	
No.	TERMINAL POINT	R	T	R	T	R	T	R	T	R	T	R	T	R	T
1	RL pen into rack	56	3	17	3	71	3	27	3	83	3	41	3	97	3
2	DA filling cap	76	20	34	17	90	19	16	19	03	20	57	18	16	19
3	RL cap	98	22	55	21	10	20	66	20	23	19	79	20	37	21
4	RL clip top	14	16	68	13	24	14	80	14	38	16	94	15	52	15
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															

SYMBOLS USED IN STUDY	DETAILS OF ADJUSTMENTS
x = fumble	

ELEMENT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TOTAL TIME IN min.	.45	2.80	2.99	2.07											
NUMBER OF READINGS	15	15	15	14											
AVERAGE	.03	.187	.199	.148											
RATING & ADJ															
BASE TIME															
1.00+ % ALLOWANCE															
ALLOWED TIME															

From Mundel. *Motion and Time Study: Principles and Practice*, p. 302.

FIG. **5.36** CONTINUOUS TIMING OF AN INSPECTION OF FOUNTAIN PENS.

$d = X - \bar{X}$ computed for each reading of the element separately before squaring and then summing

X = Individual readings of an element

$\bar{X}$ = Mean or average of all readings of an element

Σ = Sum of like items

N = Number of readings of an element

This equation may be expressed as follows for machine computation (Friden, Monroe, Marchant, etc.):

$$\mathrm{SD} = \sqrt{\frac{\Sigma X^2}{N} - \left(\frac{\Sigma X}{N}\right)^2} = \frac{1}{N}\sqrt{N\Sigma X^2 - (\Sigma X)^2}$$

Assuming that this represents the variability of a huge group of similar readings or the parent population (a commonly tenable assumption), another measure, $\mathrm{SD}_{\bar{x}}$, the standard error of the mean (or average), may be computed by (B), which indicates the probable variability of the averages of groups of N values of X about the obtained $\bar{X}$

$$\mathrm{SD}_{\bar{x}} = \frac{\mathrm{SD}}{\sqrt{N}} \tag{B}$$

The property of this last measure is such that 95 per cent of the probable values of X (average for the element) will lie within $\pm\ 2\mathrm{SD}_{\bar{x}}$ of the true average.

Hence, if $2\mathrm{SD}_{\bar{x}}$ is equal to or less than 5 per cent of $\bar{X}$, we may say the chances are at least 95 out of 100 that our average for the element to which the rating will be applied is within $\pm$ 5 per cent of the true average representing the performance we observed. If the 10 per cent criterion is used, then the above may be restated with "10 per cent" in place of "5 per cent."

As was explained earlier, both criteria can reasonably be applied to time studies.

If the selected limiting condition is not met, we may work formula (B) backwards, using the SD we first obtained, setting $2\mathrm{SD}_{\bar{x}}$ equal to 5 per cent of $\bar{X}$, and solving for N', which will indicate the number of readings that will probably be needed

Indeed, it is this last property that makes this test feasible, easy, convenient, and economical to use, after certain mathematical manipulations of the formulas have been made.

Combining formulas (A) and (B), we may state:

$$\mathrm{SD}_{\bar{x}} = \frac{\frac{1}{N}\sqrt{N\Sigma X^2 - (\Sigma X)^2}}{\sqrt{N'}}$$

Setting 5 per cent of $\bar{X}$ equal to $2\mathrm{SD}_{\bar{x}}$, we get

$$0.05\bar{X} = \frac{\Sigma X}{20N} = 2\,\frac{\frac{1}{N}\sqrt{N\Sigma X^2 - (\Sigma X)^2}}{\sqrt{N'}}$$

$$\frac{\Sigma X}{20} = \left(\frac{2\sqrt{N\Sigma X^2 - (\Sigma X)^2}}{\sqrt{N'}}\right)$$

$$\text{and } N' = \left(\frac{40\sqrt{N\Sigma X^2 - (\Sigma X)^2}}{\Sigma X}\right)^2 \tag{C}$$

where N' is the required number of readings.

This equation may be easily handled even by one who is not familiar with the mathematics of its derivation.

If the analyst prefers to set his limits as 95 chances out of 100 within $\pm$ 10 per cent, then:

$$N' = \left(\frac{20\sqrt{N\Sigma X^2 - (\Sigma X)^2}}{\Sigma X}\right)^2 \tag{C'}$$

5.4.1.4 Rating or relating performance to standard. In the preceding section, techniques were described for timing a performance of an actual operator on a job. With luck, the operator studied might meet all the requirements of the standard type and might

be working at the proper pace. Then the observed time values would require no further adjustment. In actual practice, however, the operator usually fails to perform ideally. Either he does not meet all the requirements of the standard operator, or fails to work at the pace required for standard performance, or both. Consequently, the analyst must ask himself (1) how to evaluate the performance observed as compared with the requirements given in the definition of standard used as the basis of the measurement, and (2) how to reduce this evaluation to a mathematical value that will allow the adjusting (if necessary) of the representative time values actually obtained, so as to determine a base for the standard time. These are the aims of rating.

Common rating procedures. Common time-study rating procedures can be divided into two main groups:

A. Mathematical procedures.

B. Procedures requiring judgment.

A. *Mathematical procedures.* The mathematical plans require a statistical sorting out, on the basis of the time recordings alone, of the effect of the operator's skill, aptitude, pace, relative rate of exertion, capriciousness, and so forth, from normal job variation in order to obtain a measure that would be relatively the same, regardless of whatever conditions of the above mentioned variables were in existence at the time the data were recorded. It is not surprising that this goal has never been realized. Any other mathematical method would require an outside reference point against which observed variations could be measured. The only reference point usable for such a purpose would be the standard time, but if this were known there would be no reason for the rating.

B. *Procedures requiring judgment.* Many rating systems involving judgment have been proposed and used. For the most part, they fit the following definition: "Rating is that process during which the time study man compares the performance of the operator under observation with the observer's own concept of normal performance." *

Most of these procedures require the time-study man to perform the same two basic steps:

1. He must judge the difficulty of the job and form a mental concept of what the performance of the job under observation would look like if it met the requirements of standard performance as defined.

2. The observer must appraise the actual performance under observation as compared with the concept formed in Step 1 and place a numerical value on this appraisal.

The usual guide recommended for Step 1 is "experience."

Improved rating procedure. It may be seen that the evaluation or rating of performance (as is correctly done in many rating procedures) may be reduced to a judgment of not more than two items: (a) observed pace, and (b) job difficulty. In the typical time study procedure, the time study observer first judges (b) job difficulty and then judges (a) observed pace.

What makes a more reliable time study rating procedure possible is, first of all, the realization that the difficulty of the job and its effect on maximum possible pace does not need to be judged but may be reduced to objective terms. These objective terms are based on observable phenomena, and may be reduced to tabular data as a function of strength required, amount of body used, degree of dexterity, and the like, and may be experimentally verified.

What is proposed is again a two-step rating procedure, but the steps are in the reverse of the conventional order. This is called *objective rating* and consists of the following steps:

1. Observed pace is rated against an objective pace standard, which is the

* Society for the Advancement of Management, Committee on Rating of Time Studies, *Advanced Management,* Vol. 6, July-Sept. 1941, 110.

same for all jobs. In this rating, no attention whatsoever is paid to job difficulty or to its effect on possible pace. Hence, a single pace standard may be used instead of a multiplicity of mental concepts.

2. A percentage increment is applied to adjust the resulting value subsequent to Step 1. This percentage increment is taken from experimentally determined tables of the effect of various observable factors on the exertion required at a given pace and is called "a secondary adjustment."

It has been verified experimentally that this improved rating procedure gives a more consistent concept of standard time than do the conventional procedures. It is true that the procedure requires a certain amount of preliminary activity before any time studies can be made. However, this activity need be performed only once, and the subsequent details of making time studies are less complex than in conventional rating procedures. The first part of this preliminary activity may be done in any one of three convenient ways:

1. The time-study man, or department, may choose a simple job involving almost no skills or special aptitudes and then determine experimentally the pace on this job when performance meets the requirements of standard time. This plan may require some experimentation with several operators.

2. The time-study department may make a series of films of workers working at different paces on a simple job and then ask management to select the one that represents its concept of standard pace. True, judgment must be exercised here and some original error is possible, but neither factor is critical. At least a standard of unchanging pace is set up. Also, if management wants to assume the prerogative of defining acceptable pace, it should be assumed at a high enough organizational level. The pace selected may be jointly negotiated by labor and management, in which case the accuracy with which it represents a previously accepted definition of standard is of less consequence, although the discrepancy may be discovered later through experience with the use of the selected pace. At least the pace will be acceptable to both parties, and without such mutual acceptance joint agreements concerning money per hour appear inadequate.

3. A simple job may be shown to large groups of industrial engineers (or joint labor-management groups). Then values that have been corrected for concept of standard can be averaged and used as a basis for the standard pace.

The second step suggested in the preliminary activity being outlined here is the formal selection of a film showing the standard rate of activity for any one job. This film represents the unit of measurement, or the rate of activity, for 100 per cent standard pace.* Since the record is permanently preserved, the standard rate of activity may actually be included in the labor contract. At the very least, it is available for comparison and for use in discussing ratings on an objective basis. Such can never be the case when the standard represents merely the time-study man's unanchored, mental concept of proper performance.

But a single film record is not enough for actual use. It is highly desirable to prepare *step films* that show step-by-step deviations from standard pace on the job. These records make it possible to establish markings on the scale of pace and facilitate the rating.† Once a standard pace has been selected by any one of these procedures, the step films or multi-image films can be easily pre-

* If a 60 base system is preferred, this can be identified as 60.

† All the films may be in loop form—that is, the front end may be spliced to the back to permit continuous projection for any period of time. Or the frames may be divided into different areas, each area showing a different pace, so that a group of steps may be projected simultaneously. Such films are called *multi-image step films.*

pared.* Experiments have shown† that about 6 per cent change in pace is the usual minimum detectable difference; hence, the steps on the film should approximate this magnitude. Although a considerable group of regular time-study engineers were used to obtain these data, it is possible that with further training the minimum detectable difference might be reduced. Therefore, this percentage should not be considered as an absolute value.

After the time-study man has completed this preliminary activity, he is ready to move on to the first step of the objective rating procedure. In practice, he may do one of the following:

A. Compare the observed job with the concept of the scale of standard pace that he has obtained through careful study of the step films or multi-image films.

B. Compare the observed job with the film by projecting the film into a shadow box near the job so that both may be viewed simultaneously.

C. Compare a film of the observed pace with the step films or multi-image films by projecting both films simultaneously.

Regardless of the method, the time study man must only judge whether the job being studied (actual performance or film of performance) is being performed at a pace (rate of activity) equal to any one of the step films or steps on the multi-image film, or at a pace lying between any two of the steps, and then assign a rating as indicated by the predetermined values of the steps. He pays absolutely no attention to job difficulty and its effect on the possible pace for the task.

The next part of the preliminary activity prior to using the improved rating procedure is the determination of a table of secondary adjustments so that the time obtained by time study, after being adjusted to standard pace, may be further adjusted to represent the rate of exertion included in the definition of a standard for the actual job being studied. Such a table will enable the time study observer to perform Step 2 of the two steps of the objective rating procedure.

Obviously, all jobs cannot be performed at the standard pace. Most jobs are more difficult than the job for which standard pace has been set, and some jobs are more difficult than others. For instance, some jobs involve heavier parts, closer visual work, and so forth. These variations set different limits on the pace possible for each job with a fixed rate of exertion. However, they may be evaluated objectively.

The method consists of determining the various factors that make for difficulty in the job, and evaluating their effect. This evaluation is applied as a *secondary adjustment* in computing the standard for the job, so that all the standards will be consistent in regard to attainability. These secondary adjustments may be set up as in Table 5.20.

The work of developing the values for these secondary adjustments is by no means complete, but even at the present stage of development it should be more satisfactory and reliable than leaving the adjustment to the mental evaluation of the time-study man, as is inherent in conventional rating procedures. Moreover, if inconsistencies appear when the secondary adjustments are applied, the source can be tracked down and lasting corrections can be made, a course of action that is not possible with the conventional approach. Reducing secondary adjustments to tabular form also eliminates other sources of subjectively caused variation.

Note that all the adjustments are indicated as positive increments of time above the time required at the standard pace (film loop or concept of rate of activity). Hence, the film loop or concept should, at 100 per cent pace, represent the concept of standard time on an ex-

* These films were first proposed in M. E. Mundel, *Systematic Motion and Time Study* (New York: Prentice-Hall, Inc., 1947).

† M. E. Mundel, and R. N. Lehrer, "An Evaluation of Performance Rating," *Proceedings 12th Annual National Time and Motion Study Clinic,* Industrial Management Society, Chicago, Ill., 1948.

tremely simple operation. Also, these adjustments may be used only when all jobs have been rated against a single standard pace that does not take job difficulty into account. Essentially, the developed data of Table 5.20 are used as follows:

A. Separate adjustments are made for each element.

Assume that, on a given job, for 10 per cent of the time the operator pushes a lever with a 15-pound resistance. For the rest of the time, the operator loads very light parts into a fixture. Obviously, the operator's pace will vary from the first element to the second. Consequently, each element will be adjusted separately.

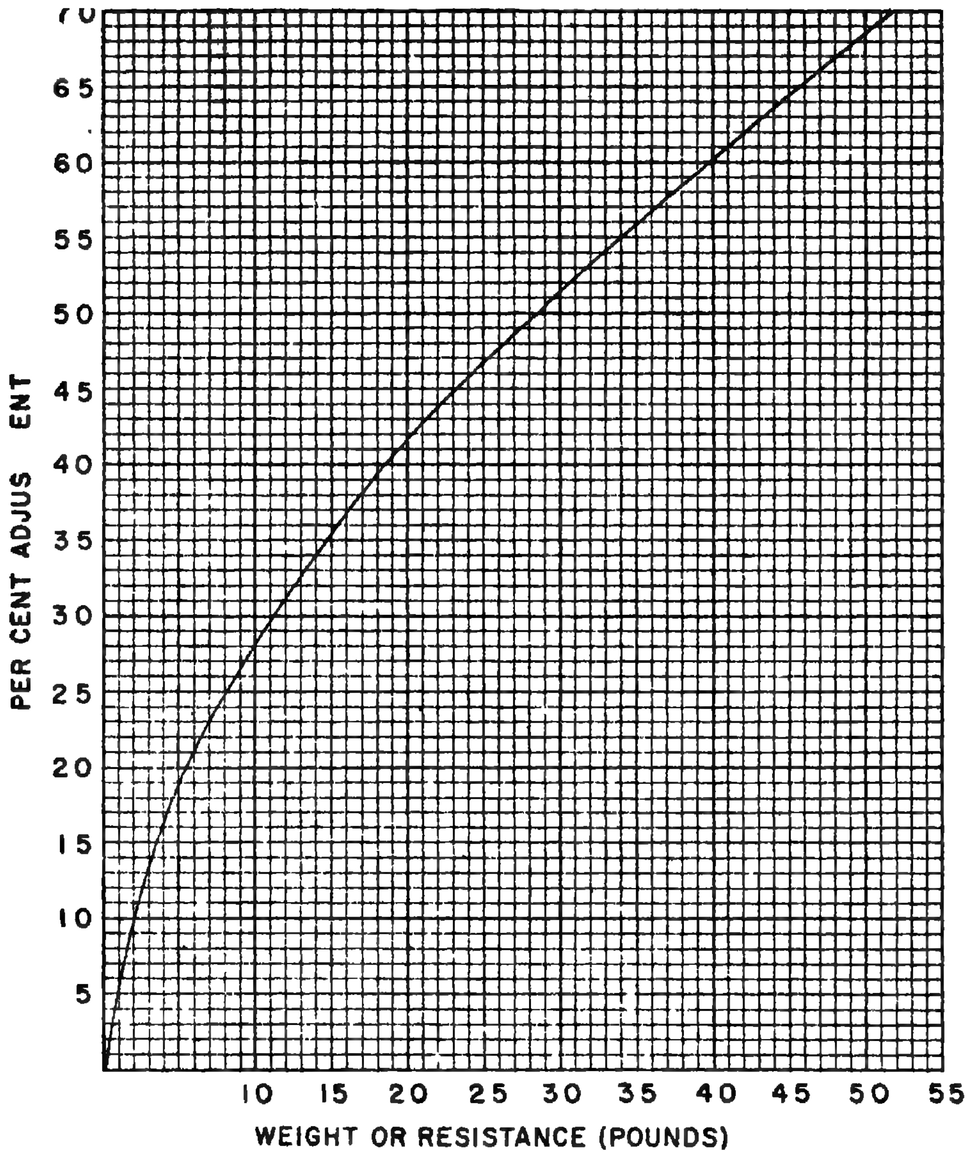
B. The total secondary adjustment for an element will be the simple sum of all the appropriate values from the scales for all the factors. As far as is known at present, these factors are additive. No complex interaction has yet been found at the element level.

C. The secondary adjustments are combined with the pace rating. If the rating is 90 per cent and the total secondary adjustment is 12 per cent, the observed time for that element will be multiplied by 0.90×1.12, or 1.01. This will give the same result that would have been obtained had the observed time first been multiplied by 0.90 to get the time required at the 100 per cent pace and then 12 per cent of the result added to the first product. The 0.12 and 0.90 cannot be added, otherwise the actual

TABLE 5.20 SECONDARY ADJUSTMENTS FOR TIME STUDIES*

Category no.	Description	Reference letter	Condition	Per cent adjustment
1	Amount of body used	A	Fingers used loosely.	0
		B	Wrist and fingers.	1
		C	Elbow, wrist, and fingers.	2
		D	Arm, etc.	5
		E	Trunk, etc.	8
2	Foot pedals	F	No pedals or one pedal with fulcrum under foot.	0
		G	Pedal or pedals with fulcrum outside of foot.	5
3	Bimanualness	H	Hands help each other or alternate.	0
		G	Hands work simultaneously doing the same work on duplicate parts.	10
4	Eye-hand coordination†	I	Rough work, mainly feel.	0
		J	Moderate vision.	2
		K	Constant but not close.	4
		L	Watchful, fairly close.	7
		M	Within 1/64 inch.	10
5	Handling requirements†	N	Can be handled roughly.	0
		O	Only gross control.	1
		P	Must be controlled, but may be squeezed.	2
		Q	Handle carefully.	3
		R	Fragile.	5
6	Weight	Identify by the letter W followed by actual weight or resistance.		Use Curve

* From Mundel, *Motion and Time Study: Principles and Practice*, pp. 343, 345.
† Note: These scales could possibly go much higher in some cases.



increment would vary with the pace observed, which would not be correct. (If a different numerical scale or scale base is used, the values used will change, but the essential procedure will not.)

D. The factors for which secondary adjustments should be added are:

1. Amount of body used.
2. Foot pedals.
3. Bimanualness.
4. Eye-hand coordination.
5. Handling or sensory requirements.
6. Weight handled or resistance encountered.

5.4.1.5 Allowances. The procedures presented thus far do not include provisions for three additional groups of adjustments that must commonly be made:

1. Allowance for personal time.
2. Allowance for irregular occurrences that may not have been time studied or that cannot be prorated
3. Allowance for machine time.

These allowances differ from the secondary adjustments in three respects: (1) usually they are applied similary to every element in the task; (2) in some categories, they may actually represent a block of time that may be accumulated from a large number of cycles to eventually provide an interval in the work period during which the worker will not be working; and (3) they relate to factors external to the job.

1. *Allowance for personal time.* This category is not to be confused with the commonly used, catch-all term *fatigue*

allowance, which, because of the many interpretations of the term *fatigue*, has led to a great deal of misunderstanding. After the time-study observations have been adjusted either by subjective ratings or objective ratings (including secondary adjustments), the result is supposedly a time value that will permit the operator to produce work in this time, or less, throughout the normal work period, so far as the internal work of the operation is concerned. However, note that no attention is paid to personal needs (among other items) or to the effect of external conditions upon personal needs.

A person usually cannot work through a normal industrial work period without attending to personal needs. The amount of time required will be affected by the conditions surrounding the work: less when the surroundings are comfortable and quiet, and more when they are hot, dusty, or noisy. Many plants have a set schedule to provide for personal time during the working day.

2. *Allowance for irregular occurrences.* It is desirable to study and rate all irregular occurrences and to prorate them so that they are properly apportioned to each cycle. However, it is extremely difficult to handle some occurrences in this manner. For example, let us assume a sewing-machine operator must clean his machine at the end of each day. Perhaps this takes five minutes. It is hardly proper to charge all this time to the last job of the day. Nor is it feasible to prorate it to a value that is added to each cycle, since the operator may work on several jobs each day and each job may have a different total cycle time. Yet the cost of these five minutes should somehow be distributed among the jobs. Consequently, some adjustment must be made that will permit the accumulation of five minutes during the day as part of the standards. Similar allowances may have to be made for tool and machine maintenance, and the like.

A unique method of determining and evaluating irregularly occurring elements is described as "ratio-delay" studies. These are made as follows:

The observer passes the work stations at random intervals. Each time he passes some predetermined spot, he notes on a check sheet what is occurring. The following precautions should be observed:

1. Only homogeneous groups should be combined in a single study; that is, similar observations on similar machines.
2. Fewer than 1,000 observations are of little value. Best results are obtained in the range from 2,500 to 3,500 observations.
3. Observations must be at random intervals . . . and independent.
4. Observations should be made throughout all hours of a working day, and over a period of not less than two weeks.*

The percentage of occurrences of each type of activity in the sample of observations indicates the percentage of time spent at it. When these percentages are reduced to minutes per working day, they can be used as a basis for determining percentage allowances to be added to the standard time for all elements.

As an alternate procedure, a mechanical or electrical recorder is placed on the machine to provide an accurate time measurement of each delay. In an accompanying log, the foreman or worker notes the reason for each delay. These two records may later be analyzed to provide a basis for allowances for irregular occurrences.

It is strongly suggested, however, that when the irregular work can be directly attributed to a specific job, and when a rate of occurrence during that job can be determined, the time value should be handled as an irregular element. Otherwise the allowances for irregular elements may get out of hand and may eventually lead to sizable inconsistencies in the comparative difficulty of standards for different jobs. Extended time studies can be made in which the work is divided only into productive work and delays. Either a stop watch or a memomotion camera can be used. With a camera, more than one machine can be observed at a time,

* J. S. Petro, "Using Ratio-Delay Studies To Set Allowances," *Factory*, October 1948, 94.

with no loss of accuracy. Such studies provide a basis for determining accurate allowances.

3. *Allowance for machine time*. There are some who will feel that the adding of an additional allowance, so as to permit an equal production increment over standard on all jobs, to jobs where the machine controls in excess of 45 per cent of the cycle (the percentage at which the rest effect ceases to make up for the lack of production opportunity) is a "softening up" of the standard. This attitude is worth examining from two points of view: first, as if no incentives were to be applied; and second, with incentives applied.

In either case, production in excess of standard should be expected from the typical worker. The standard should be set below expected performance in order to provide a situation that leads to "attainment" rather than to "implied frustration."

When no incentives are used, an adjustment to make equal the excess attainment possible on all jobs will enhance the value of the standards for most uses, since they may be used similarly for scheduling and the men in the shop may inter-compare their performance with one another on a simple basis. This is their usual concept of equity and is hardly worth disturbing.

If incentives are in use, an incentive increment may be provided for machine jobs that is equal to the increment provided for jobs that involve only hand time. Or an even higher incentive increment may be established, since the actual burden rate is higher on the machine jobs. Certainly some adjustment must be made if the job hierarchy is not to be completely upset.

Table 5.21 gives a schedule of allowances, including a set of values for equalizing the over-standard production attainable on jobs that are partly machine-controlled. These values are based on a standard that makes 30 per cent over-standard production typically expectable. The values of category three would have to be altered if any other percentage were introduced.

For tasks where the operator works during part of the machine cycle, further computations are necessary before the values from all three categories are added to obtain the allowance. Let us assume we have a task of which 60 per cent is controlled by the machine. However, since the operator prepares a load during part of this time, he actually works 70 per cent of the cycle. According to Table 5.21, an operator with a cycle of 70 per cent hand time would receive a 0 allowance; the implication is that he could work fast enough during the 70 per cent to exceed the standard by 30 per cent without any allowance. However, his excess productivity during 40 per cent of the cycle would show up How fast he went during the remainder of the hand time would be of no value, since the machine controls the production after the 40 per cent for hand time is completed. Conseqeuntly, instead of gaining 30 per cent, he would gain only $30 \times 40/70 = 17$ per cent. An allowance of $30 - 17$, or 13 per cent, would have to be added to bring this standard to a level he could exceed by 30 per cent without greater exertion than a 100 per cent manually paced operator. Note that this allowance is larger, as it should be, than the 6 per cent allowance that would accompany a job involving 60 per cent machine time during all of which the operator rested. Other situations may be evaluated in a similar manner.

Table 5.21 is only suggestive. The nature of the allowance or the meagerness of data may require that some of the items be recomputed or negotiated before being used in an actual application.

5.4.1.6 Summary. A time study complete with allowances, and with the final calculations made and transferred to the front, is shown in Fig. 5.37 a and b. The two calculations at the bottom of the front of the sheet are designed to summarize the effect of the ratings and allowances for the time-study supervisor. The "production anticipated at standard" is computed on the basis of the allowed cycle time. The "production during study" is computed on the basis of

TABLE 5.21 ALLOWANCE TABLE*

Category	Reference letter	Condition	Time in minutes in 8-hour work spell †	Per cent
1—Personal ‡	S	Comfortable	15	
	T	Warm or slightly disagreeable	20	
	U	Hot, dusty, noisy, etc.	50	
	SP	Special or unusual	As required	
2—Irregular (Cleanup, tool, etc.)	Use name	Evaluate	Suitable	

To reduce the total of time from categories 1 and 2 to a per cent value, use an equation in which: A = minutes per work day; B = minutes personal allowance per work day; C = minutes irregular allowance per work day.

$$\frac{B + C}{A - (B + C)} \times 100$$

3—Per cent of base time of cycle controlled by the machine **	V followed by per cent controlled by machine	100 of cycle controlled by machine		30
		95		27
		90		24
		85		20
		80		17
		75		14
		70		11
		65		9
		60		6
		55		4
		50		3
		45 or less		0

* From Mundel, *Motion and Time Study: Principles and Practice*, p. 359.
† Divided into two 4-hour work spells by a lunch period.
‡ If rest spells are used, as total time of rest pauses instead of this if rest pauses are meant as substitutes r personal time taken at will.
** These per cent allowances are for standards with a 30 per cent anticipated typical production increment.

the total average time (with irregular elements prorated as necessary). These two values sum up the relationship between observed performance and anticipated performance; they are often of great aid in indicating when unusual or difficult situations may arise from the installation of the standard.

5.4.2 Synthesized standards. Procedures for synthesizing standards may be divided into two main groups: (1) procedures that use standard elements and that are generally designed for use with a given type of work, and (2) procedures that are based on smaller action units to permit more general application. Each of these two types is discussed separately.

5.4.2.1 Synthesized standards from standard elements. To develop the basic element times from which standards may be synthesized, it is necessary to have a series of time studies of similar jobs. The time study data must have the following characteristics:

A. Based on an adequate written standard practice with well-defined element end points.
B. Broken down into similar elements.

No.	ELEMENTS: TERMINAL POINT	1 R	1 T	2 R	2 T	3 R	3 T	4 R	4 T	5 R	5 T	6 R	6 T	7 R	7 T	8 R	8 T
1	Release ring	07	7	33	6	62	7	86	6	16	7	43	6	71	7	98	6
2	Pick up assembly	16	9	43	10	70	8	76	10	M	X	52	9	80	9	07	9
3	let go of weight	22	6	50	7	77	7	03	7	32	X	59	7	86	6	13	6
4	let go of lever	27	5	55	5	82	5	09	6	37	5	64	5	92	6	18	5
5	Return from					180	98										
6	Stockroom																
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	

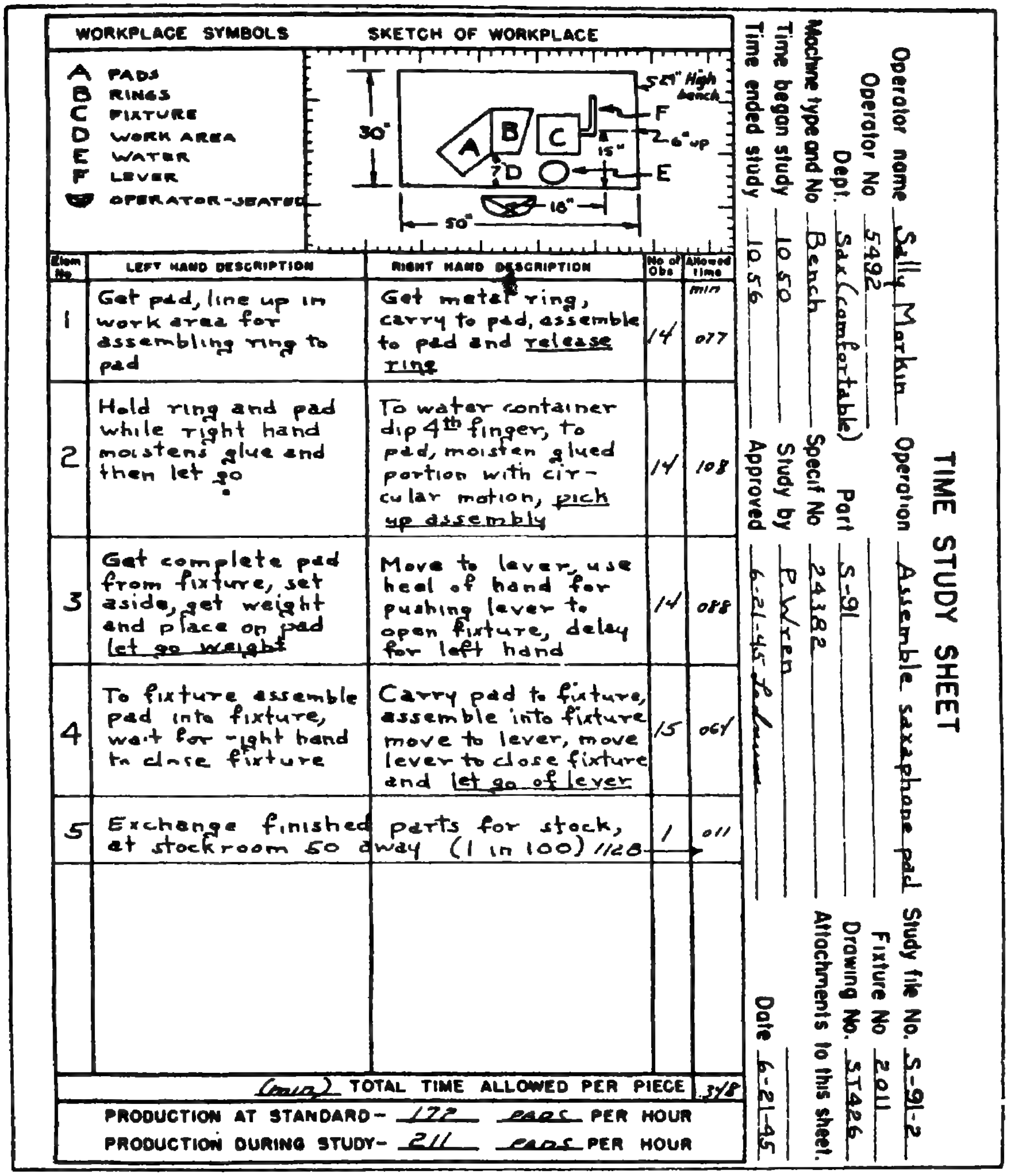
No.	ELEMENTS: TERMINAL POINT	9 R	9 T	10 R	10 T	11 R	11 T	12 R	12 T	13 R	13 T	14 R	14 T	15 R	15 T
1	Release ring	24	6	50	6	77	7	16	16	44	7	71	6	98	7
2	Pick up assembly	32	8	59	9	87	10	25	9	53	9	80	9	08	10
3	let go of weight	39	7	66	7	95	6	32	7	59	6	86	6	15	7
4	let go of lever	44	5	72	6	00	5	37	5	65	6	91	5	20	5
5	Return from														
6	Stockroom														
7															
8															
9															
10															
11															
12															
13															
14															
15															

SYMBOLS USED IN STUDY	DETAILS OF ADJUSTMENTS: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
f - fumble, not necessary M - reading missed Allowances $\frac{18}{480-13} = 4\%$	C - 2 F - 0 N - 0 J - 2 N - 0 W6 - 0 4	C - 2 F - 0 N - 0 T - 2 N - 0 W6 - 0 4	C - 2 F - 0 N - 0 J - 2 N - 0 W4 - 15 19	C - 2 F - 0 N - 0 J - 2 N - 0 W2 - 8 12	E - 8 F - 0 N - 0 I - 0 N - 0 W4 - 15 23					ALL. PERS DAILY CLEAN-UP	- 5 - 15 min - $\frac{3}{18 \text{ min}}$	/8 hr			

ELEMENT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TOTAL TIME IN min.	.91	1.28	.92	.79	.98										
NUMBER OF READINGS	14	14	14	15	1										
AVERAGE	.065	.091	.066	.053	.98										
RATING & ADJ	110 / 04	110 / 04	105 / 19	105 / 12	90 / 23										
BASE TIME	.074	.104	.085	.062	1.085										
1.00+ % ALLOWANCE	1.04	1.04	1.04	1.04	1.04										
ALLOWED TIME	.077	.108	.088	.064	1.128										

From Mundel, *Motion and Time Study: Principles and Practice*, p. 360.

FIG. **5.37a** COMPLETED REAR OF TIME STUDY FORM FOR TASK OF ASSEMBLE SAXOPHONE PAD.



TIME STUDY SHEET

Operator name Sally Markin
Operator No 5492
Dept. Sax (comfortable)
Machine type and No Bench
Time began study 10.50
Time ended study 10.56
Operation Assemble saxaphone pad
Part S-91
Specif No 24382
Study by P. Wren
Approved 6-21-45
Study file No. S-91-2
Fixture No 2011
Drawing No. ST426
Attachments to this sheet
Date 6-21-45

WORKPLACE SYMBOLS

A PADS
B RINGS
C FIXTURE
D WORK AREA
E WATER
F LEVER
OPERATOR-SEATED

SKETCH OF WORKPLACE

Elem No	LEFT HAND DESCRIPTION	RIGHT HAND DESCRIPTION	No of Obs	Allowed time min
1	Get pad, line up in work area for assembling ring to pad	Get metal ring, carry to pad, assemble to pad and release ring	14	.077
2	Hold ring and pad while right hand moistens glue and then let go	To water container dip 4th finger, to pad, moisten glued portion with circular motion, pick up assembly	14	.108
3	Get complete pad from fixture, set aside, get weight and place on pad let go weight	Move to lever, use heel of hand for pushing lever to open fixture, delay for left hand	14	.088
4	To fixture assemble pad into fixture, wait for right hand to close fixture	Carry pad to fixture, assemble into fixture move to lever, move lever to close fixture and let go of lever	15	.064
5	Exchange finished parts for stock, at stockroom 50 away (1 in 100) 1128		1	.011

(min) TOTAL TIME ALLOWED PER PIECE .348

PRODUCTION AT STANDARD– 172 pads PER HOUR

PRODUCTION DURING STUDY– 211 pads PER HOUR

From Mundel, *Motion and Time Study: Principles and Practice*, p. 361.

FIG. **5.37b** COMPLETED FRONT OF TIME STUDY FORM FOR TASK OF ASSEMBLE SAXOPHONE PAD.

C. Similar methods used in the tasks observed.

D. Similar equipment used in the tasks observed.

E. Homogeneous elements.

F. Rated to a uniform rate of activity.

G. Comparable allowances used.

In developing standard data for a group of jobs, the following types of elements may be encountered (and should be isolated):

A. Constant elements, indentical from job to job.

B. Variable elements, similar from job to job but varying in difficulty with the size, shape, and so forth, of the work. These may involve handwork or work with a machine, if the machine work is operator-paced.

C. Machine elements, mechanically controlled by the feed, speed, length of cut, welding current, thickness of material, and so forth.

These three types of elements may exhibit any of the following three characteristics of occurrence:

1. Repeated the same number of times in each job.

2. Repeated a different number of times in each job.

3. Appear in some jobs and not in others.

The data should be obtained and handled in the following manner:

1. Obtain time studies for as wide a range of jobs as possible, within a given group of similar jobs.

2. Be sure the time study data meet the criteria previously stated.

3. Summarize the time studies on a summary form. (The columns usually are for given elements, and the lines for given jobs. It is customary to list also, on each line, all physical characteristics peculiar to the item handled on that job --i.e., weight, volume, etc.)

4. Ascertain which elements are constant and which are variable (a function of some characteristic of the product).

5. For the constant elements, determine the average standard time. Statistical techniques may be used to examine the significance of the variability of the data for such elements.

6. For the variable elements:

   a. Determine, on a logical basis, what job characteristic or characteristics they are a function of.

   b. Plot on a graph the time for each element against a variable or variables. (Note that sometimes the variables may interact or act in combination.)

   c. Fit a smooth curve or curves to the points plotted.

This curve (or curves) may or may not pass close to the points. (If two variables control the values, a series of parallel curves may be necessary.) If the curve does not fit the points reasonably well, any of the following causes may be responsible:

(1) The time studies were incorrectly or inconsistently rated.

(2) Other variables as well as those plotted also affected the time.

(3) The method varied.

(4) An incorrect variable was used.

Each possibility should be investigated and evaluated. Note that even if the values fall along a smooth curve, it is still possible that two types of errors occurred that compensate for each other, although this is not likely. The variables used should be reasonable. When a reasonable fit with a smooth curve cannot be obtained, or when the reason for lack of fit cannot be explained with certainty, the investigations and study should continue until such can be done. Haphazard basic times are never justifiable. A good criterion is, "Could this be explained in a manner that would be acceptable to the typical worker?" This criterion rules out the use of complicated mathematics in the final statement, although the careful worker may choose to fit his curves mathematically. In many cases, only a straight line is justifiable, and it is often fitted by the method of least squares. This method, however, is designed to determine the line with the best fit and not to justify the line.

   d. If the variable is discrete—that is, if it has only definite steps between two limits—prepare a table for the range of jobs covered. If the variable is continu-

ous—that is, if it has an infinite number of possibilities between two limits—prepare a graph.

Some workers prepare a formula for the function. But if the formula is at all complex, it is often considered undesirable,* because:

(1) It may complicate the determination of standard. Of course, the analyst may prepare a very complex equation and use it himself either to plot the curve or to find the basic time for step-by-step values of the variable, and then prepare a detailed table for actual use. However, the questions may well be asked, "Are the data really as accurate as all this refinement would suggest? Could not acceptable values be read off the curve sketched for the data?" Also, since a table has a finite number of steps, the values nearest the actual condition of the variable in a specific application must be used as a reasonably good approximation; hence, extreme accuracy cannot be obtained.

(2) It tends to befuddle most of the working groups to whom it is "explained."

(3) It requires additional work that does not usually add utility to the basic times.

(4) It may lead to extrapolation beyond the range covered by the data, and thus cause serious errors.

5.4.2.2 Synthesized standards from basic motion times. In some cases, it is either inconvenient or impossible to engineer a standard directly (the job may not be in operation), and studies of similar work from which applicable element times could be extracted or developed may not be available. Further, it may be desirable to develop a standard by another means as an independent basis of comparison for stop-watch standards. However, individual motion times for units as small as therbligs are not independent values; rather, they are affected by the pattern of motions in which they occur. Although in the method given here, corrections for this effect are made, the data given are not to be considered absolute values nor is the correction to be considered complete. Reference should be made to Art. 5.5 (Sources of error), which offers suggestions for the intelligent use of these data.

Source of the data. The data given in this section were developed by Dr. I. P. Lazarus and are reproduced with his permission. Using the camera timing technique described in Art. 5.4.1, he collected numerous time studies of industrial operations. These pictures were taken at 1,000 frames per minute to permit later rating against the multi-image loops described in Art. 5.4.1. The reliability of the samples was checked using statistical methods. The rated therblig times were treated in the manner described in Art. 5.4.2, Item 6.

The data developed were tested by (1) reconstituting the original jobs, and (2) synthesizing a second group of new tasks and comparing the standards thus developed against standards set independently by stop-watch time study and objective rating procedures. The differences between these latter pairs of values were in the order of the usual discrepancy between pairs of independently set time studies.

Variables evaluated. When all data were reduced to a common pace (see Art. 5.4.1), the therbligs *TE* and *TL* (see Table 5.8) were found to be an exponential continuous function of distance.

Grasp was a discrete function of condition of grasp. Four types were isolated:

1. Contact: control gained by mere contact.
2. Contact pinch: control gained by contact with one or more fingers sliding the object into a position so that the thumb could oppose them.
3. Pinch: control gained by maneuver-

* This is not true of the common practice of using a simple mathematical formula to show how the elements are combined into a standard. Since such a formula usually involves no higher mathematics, it is often a helpful device.

TABLE **5.22** BASIC TIME TABLES IN 1/100,000 MINUTES; (.00001 MIN)*

Time for TRANSPORT LOADED, TRANSPORT EMPTY, and WALKING

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Distance (inches)	Basic Time	Bx1.01	Bx1.02	Bx1.03	Bx1.04	Bx1.05	Bx1.06	Bx1.07	Bx1.08	Bx1.09	Bx1.10	Bx.10	Bx.20	Bx.30	Bx.40	Bx.50	Bx.60	Bx.70	Bx.80	Bx.90
1	172	174	175	177	179	181	182	184	186	187	189	17	34	52	69	96	103	120	138	155
2	243	245	248	250	253	255	258	260	262	265	267	24	49	73	97	122	146	170	194	219
3	297	300	303	306	309	312	315	318	321	324	327	30	59	89	119	149	178	208	238	267
4	343	346	350	353	357	360	364	367	370	374	377	34	69	103	137	172	206	240	274	309
5	384	388	392	396	399	403	407	411	414	419	422	38	77	115	154	192	230	269	307	346
6	420	424	428	433	437	441	445	449	455	458	462	42	84	126	168	210	252	294	336	378
7	454	459	463	468	472	477	481	486	490	495	499	45	91	136	182	227	272	318	363	409
8	485	490	495	500	504	509	514	519	524	529	534	49	97	146	194	243	291	340	388	437
9	515	520	525	530	536	541	546	551	556	561	567	52	103	155	206	258	309	361	412	464
10	543	548	554	559	565	570	576	581	586	592	597	54	109	163	217	272	326	380	434	489
11	569	575	580	586	592	597	603	609	615	620	626	57	114	171	228	285	341	398	455	512
12	594	600	606	612	618	624	630	636	642	647	653	59	119	178	238	297	356	416	475	535
13	619	625	631	638	644	650	656	662	669	675	681	62	124	186	248	310	371	433	495	557
14	642	648	655	661	668	674	681	687	693	700	706	64	128	193	257	321	385	449	514	578
15	665	672	678	685	692	698	705	712	718	725	732	67	133	200	266	333	399	466	532	599
16	686	693	700	707	713	720	727	734	741	748	755	69	137	206	274	343	412	480	549	617
17	707	714	721	728	735	742	749	756	764	771	778	71	141	212	283	354	424	495	566	636
18	728	735	743	750	757	764	772	779	786	794	801	73	146	218	291	364	437	510	582	655
19	748	755	763	770	778	785	793	800	808	815	823	75	150	224	299	374	449	524	598	673
20	767	775	782	790	798	805	813	821	828	836	844	77	153	230	307	384	460	537	614	690
21	786	794	802	810	817	825	833	841	849	857	865	79	157	236	314	393	472	550	629	707
22	805	813	821	829	837	845	853	861	869	877	886	81	161	242	322	403	483	564	644	725
23	823	831	839	848	856	864	872	881	889	897	905	82	165	247	329	412	494	576	658	741
24	841	849	858	866	875	883	891	900	908	917	925	84	168	252	336	421	505	589	673	757
25	858	867	875	884	892	901	909	918	927	935	944	86	172	257	343	429	515	601	686	772
26	875	884	893	901	910	919	928	936	945	954	963	88	175	263	350	438	525	613	700	788
27**	892	901	910	919	928	937	946	954	963	972	981	89	178	268	357	446	535	624	714	803
28	908	917	926	935	944	953	962	972	981	990	999	91	182	272	363	454	545	636	726	817
29	924	933	942	952	961	970	979	989	998	1007	1016	92	185	277	370	462	554	647	739	832
30	940	949	959	968	978	987	996	1006	1015	1025	1034	94	188	282	376	470	564	658	752	846
31	955	965	974	984	993	1003	1012	1022	1031	1041	1051	96	191	287	382	478	573	669	764	860
32	971	981	990	1000	1010	1020	1029	1039	1049	1058	1068	97	194	291	388	486	583	680	777	874
33	986	996	1006	1016	1025	1035	1045	1055	1065	1075	1085	99	197	296	394	493	592	690	789	887
34	1001	1011	1021	1031	1041	1051	1061	1071	1081	1091	1101	100	200	300	400	501	601	701	801	901
35	1015	1025	1035	1045	1056	1066	1076	1086	1092	1106	1117	102	203	305	406	508	609	711	812	914
36	1029	1039	1050	1060	1070	1080	1091	1101	1111	1122	1132	103	206	309	412	515	617	720	823	926
37	1044	1054	1065	1075	1086	1096	1107	1117	1128	1138	1148	104	209	313	418	522	626	731	835	940
38	1058	1069	1079	1090	1100	1111	1121	1132	1143	1153	1164	106	212	317	423	529	635	741	846	952
39	1072	1083	1093	1104	1115	1126	1136	1147	1158	1168	1179	107	214	322	429	536	643	750	858	965
40	1085	1096	1107	1118	1128	1139	1150	1161	1172	1183	1194	109	217	326	434	543	651	760	868	977
41	1099	1110	1121	1132	1143	1154	1165	1176	1187	1198	1209	110	220	330	440	550	659	769	879	989
42	1112	1123	1134	1145	1156	1168	1179	1190	1201	1212	1223	111	222	334	445	556	667	778	890	1001
43	1125	1136	1148	1159	1170	1181	1193	1204	1215	1226	1238	113	225	338	450	563	675	788	900	1013
44	1138	1149	1161	1172	1184	1195	1206	1218	1229	1240	1252	114	228	341	455	569	683	797	910	1024

45	1151	1163	1174	1186	1197	1209	1220	1232	1243	1255	1266	115	230	345	460	576	691	806	921	1036
46	1164	1176	1187	1199	1211	1222	1234	1245	1257	1269	1280	116	233	349	466	582	698	815	931	1048
47	1176	1188	1200	1211	1223	1235	1247	1258	1270	1282	1294	118	235	353	470	588	706	823	941	1058
48	1189	1201	1213	1225	1237	1248	1260	1272	1284	1296	1308	119	238	357	476	595	713	832	951	1070
** Use 27" for WALKING, per standard pace. For WALKING by distance, per foot, use line below.																				
per foot	396	400	404	408	412	416	420	424	428	432	436	40	79	119	158	198	238	277	317	356
Time for GRASP																				
Contact	174	176	177	179	181	183	184	186	188	190	191	17	35	52	70	87	104	122	139	157
Contact-Pinch	278	281	284	286	289	292	295	297	300	303	306	28	56	83	111	139	167	195	222	250
Pinch	357	361	364	368	371	375	378	382	386	389	393	36	71	107	143	179	214	250	286	321
Wrap	566	572	577	583	589	594	600	606	611	617	623	57	113	170	226	283	340	396	453	509
Time for POSITION																				
1st Degree	200	202	204	206	208	210	212	214	216	218	220	20	40	60	80	100	120	140	160	180
2nd Degree	223	225	227	230	232	234	236	239	241	243	245	22	45	67	89	112	134	156	178	201
3rd Degree	311	314	317	320	323	327	330	333	336	339	342	31	62	93	124	156	187	218	249	280
4th Degree	412	416	420	424	428	433	437	441	445	449	453	41	82	124	165	206	247	288	330	371
5th Degree	556	562	567	573	578	584	589	595	600	606	612	56	111	167	222	278	334	389	445	500
Time for ASSEMBLE																				
1/4 inch†	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
3/8	24	24	24	25	25	25	25	26	26	26	26	2	5	7	10	12	14	17	19	22
1/2	89	90	91	92	93	93	94	95	96	97	98	9	18	27	36	45	53	62	71	80
5/8	154	156	157	159	160	162	163	165	166	168	169	15	31	46	62	77	92	108	123	139
3/4	219	221	223	226	228	230	232	234	237	239	241	22	44	66	88	110	131	153	175	197
7/8	284	287	290	293	295	298	301	304	307	310	312	28	57	85	114	142	170	199	227	256
1	349	352	356	359	363	366	370	373	377	380	384	35	70	105	140	175	209	244	279	314
1 1/8	414	418	422	426	431	435	439	443	447	451	455	41	83	124	166	207	248	290	331	373
1 1/4	479	484	489	493	498	503	508	513	517	522	527	48	96	144	192	240	287	335	383	431
1 3/8	544	549	555	560	566	571	577	582	588	593	598	54	109	163	218	272	326	381	435	490
1 1/2	609	615	621	627	633	639	646	652	658	664	670	61	122	183	244	305	365	426	487	548
1 5/8	674	681	687	694	701	708	714	721	728	735	741	67	135	202	270	337	404	472	539	607
1 3/4	740	747	755	762	770	777	784	792	799	807	814	74	148	222	296	370	444	518	592	666
1 7/8	805	813	821	829	837	845	853	861	869	877	886	81	161	242	322	403	483	564	644	725
2	870	879	887	896	905	914	922	931	940	948	957	87	174	261	348	435	522	609	696	783
2 1/8	935	944	954	963	972	982	991	1000	1010	1019	1029	94	187	281	374	468	561	655	748	842
2 1/4	1000	1010	1020	1030	1040	1050	1060	1070	1080	1090	1100	100	200	300	400	500	600	700	800	900
2 3/8	1065	1076	1086	1097	1108	1118	1129	1140	1150	1161	1172	107	213	320	426	533	639	746	852	959
2 1/2	1130	1141	1153	1164	1175	1187	1198	1209	1220	1232	1243	113	226	339	452	565	678	791	904	1017
2 5/8	1195	1207	1219	1231	1243	1255	1267	1279	1291	1303	1315	120	239	359	478	598	717	837	956	1076
2 3/4	1260	1273	1285	1298	1310	1323	1336	1348	1361	1373	1386	126	252	378	504	630	756	882	1008	1134
2 7/8	1325	1338	1352	1365	1378	1391	1405	1418	1431	1444	1458	133	265	398	530	663	795	928	1060	1193
3	1391	1405	1419	1433	1447	1461	1474	1488	1502	1516	1530	139	278	417	556	696	835	974	1113	1252
† 1/4 inch and less of ASSEMBLE is contained in POSITION; at least it could not be evaluated as a separate value.																				
Time for DISASSEMBLE																				
All	476	481	486	490	495	500	505	509	514	519	524	48	95	143	190	238	286	333	381	428
Time for RELEASE LOAD																				
All	189	191	193	195	197	198	200	202	204	206	208	19	38	57	76	95	113	132	151	170

* Adapted from Irwin P. Lazarus, "A System of Predetermined Human Work Times," Ph.D. Thesis, Purdue Univ., 1952.

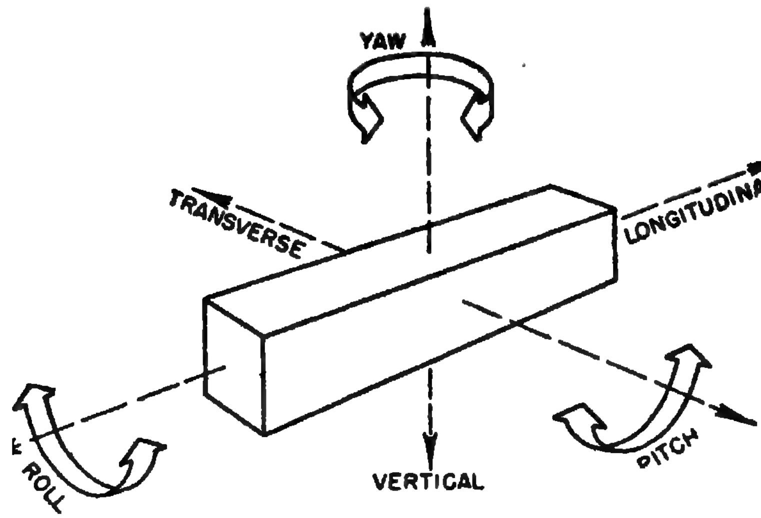


FIG. 5.38 THE SIX SOURCES OF RESTRICTIONS POSSIBLE WITH THE THERBLIG POSITION.

ing the hand so that the thumb and one or more fingers came into opposition on the object.

4. Wrap: control gained by fingers and palm coming into opposition on object.

Position was a function of the number of degrees of positioning required. A degree was defined as a restriction in a dimension or orientation that had to be provided by the operator; there were six possible sources of restriction, but no more than five were found to occur at once. The six sources are shown in Fig. 5.38.

Assemble was found to be a function of the distance of restricted movement.

Disassemble and *release load* appeared to be constants. The interactions and interdependence of the therbligs were adjusted for by grouping them into elements and by applying secondary adjustments (see Table 5.20, and 5.41) to the elements as a whole. Consequently, it appears that the therblig times are a function of (at least) the variables given under each therblig, the variables covered by the secondary adjustments of Table 5.20, and the context of the element in which they occur.

Basic motion time values. The data determined by the procedure described above are given, in a form suitable for use in synthesizing a task, in Table 5.22.

Method of use. To develop a standard from the data given in Table 5.22 the following steps should be followed:

A. The actual or contemplated workplace or work area should be carefully dimensioned, as shown in Fig. 5.39, and the nature of what is to be accomplished should be summarized.

B. Using a form such as that shown in Fig. 5.40, each element should be detailed in terms of constituent therbligs. Elements of the magnitude of stop-watch time-study elements should be used to allow for therblig interactions. The conditions of each therblig should be carefully evaluated and noted in the proper column in terms of the variables used in Table 5.22.

C. Using Table 5.20, the secondary adjustment for each element should be computed using the proper columns of Fig. 5.40.

D. Using Table 5.22, the time for each therblig, for each hand, should be entered on the computation form, as in Fig. 5.40. (The job shown in Fig. 5.39 was used.) Note that Table 5.22 gives basic times, the basic times plus 1 per cent increments to 1.10 of the basic time, and then successive 10 per cent steps from .10 to .90 of the basic time. If the secondary adjustment is 10 per cent or less, the therblig time may be entered on a form such as that in Fig. 5.40, with only one entry. If the secondary adjustment exceeds 10 per cent, two

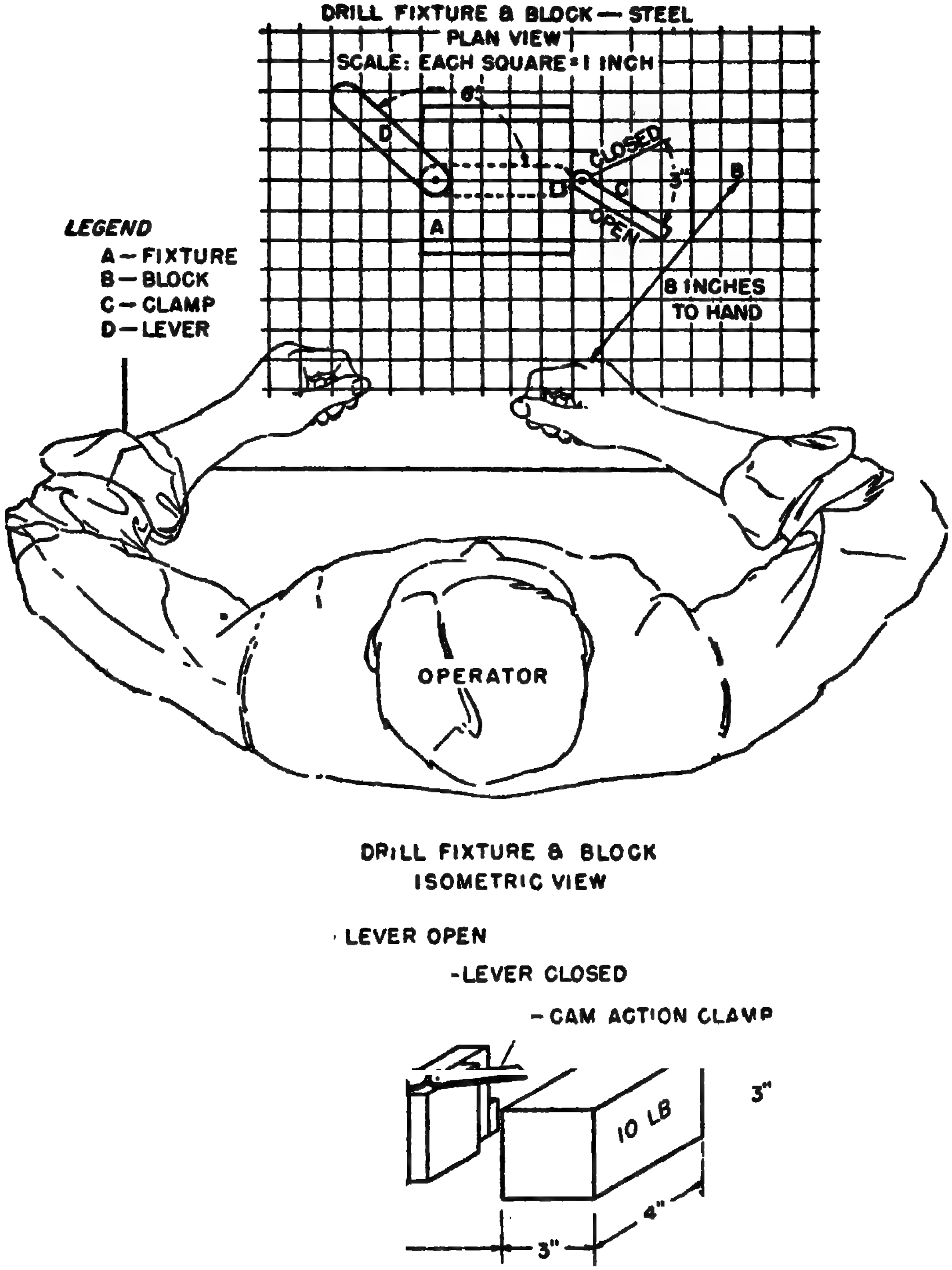


FIG. 5.39 SKETCH OF WORKPLACE.

entries should be made; for a secondary adjustment of 23 per cent, for example, both the 1.03 multiple (the value from column E) and the multiple .20 (from column N) should be entered in the two time entry spaces for each therblig provided on the form in Fig. 5.40. Unavoidable delays, holds, and so forth, take their value from the controlling hand. For *select*, which is basically a therblig with no controls, twice the *grasp* time should be used as an approximation.

E. The total element time is taken as that required by the hand with the longest or controlling time.

F. On a form such as that shown in

1 Sheet of
3 Sheets
2319 6 March 1953 Job number and date

ORDNANCE MANAGEMENT ENGINEERING TRAINING PROGRAM
WORK SHEET FOR PREDETERMINED APPROXIMATE PERFORMANCE TIME

Element number	LEFT HAND DETAILS: What, from, to, etc.	Therblig	Condition of the therblig	Time value	Time value	Condition of the therblig	Therblig	RIGHT HAND DETAILS: What, from, to, etc.	FOR SIGN.: Adj. cat.	Adj % and total
	From H to fixture	TE	8"	504 / 146	504 / 146	8"	TE	From H to block	C	2
	Fixture	G	P	371 / 107	371 / 107	P	G	Block	F H	0 0
	Fixture	H			504 / 146	8"	TL	To fixture with block	J P	2 2
1					578 / 167	5th	P	Block to fixture	W_{10}	28
					363 / 105	1"	A	Block into bottom of fixture		34
					197 / 57		RL	Block in fixture		
					3245					
	From fixture to lever	TE	4"	374 / 34	374 / 34	4"	TE	From block to clamp	C	2
	Lever D	G	C	190 / 17	617 / 57	W	G	Clamp C	F H	0 0
2	Lever to closed location	TL	6"	458 / 42			H		I O	0 1
	Lever	RL		206 / 19	258	*		* To balance	W_4	16
	While RH locks clamp	UD			324 / 30	3"	TL	Cam clamp to lock		19
					206 / 19		RL	Cam clamp		
					1919					

FIG. 5.40 ELEMENT WORK SHEET FOR USE WITH PREDETERMINED APPROXIMATE WORK TIMES. (FILLED IN FOR JOB OF FIG. 5.39.)

Fig. 5.41, the elements and job information are summarized, the allowances computed (see Art. 5.4.1.5), and then the standard is computed. (The job of Fig. 5.39 was again used in this illustration.)

Since the original data were developed by the procedure described under 5.41, the standard that results from the use of these data should be, within limits, comparable to the standard described in that article. This synthesizing procedure is particularly useful for planning new work or for comparing contemplated, alternative methods.

5.4.3 Statistical standards. These are usually determined by the following procedure:

A. Defining the standard of measurement in terms of some time statistic.

B. Selecting an apparently related work unit.

C. Determining the relationship between A and B.

Statistical standards are usually used for management control purposes rather than for detailed or incentive use.

5.4.3.1 Defining the standard of performance. The time statistic selected may be the mean or arithmetic average, one of the quartile boundaries, or some function of the mean and the standard deviation. Since all these measures are calculated from data on past performance (usually a considerable period and number of people are involved), the statistical standard may be said to be a function of past performance. For example, standard time for an activity may be defined as the average time previously taken, per work unit, over the past two months or over the best two months in the past year, and so forth.

Concerning statistical standards, Mr. W. R Vogel, Ordnance Manpower Control Specialist, has written:

> If we set a performance standard statistically using the arithmetic mean, we

ORDNANCE MANAGEMENT ENGINEERING TRAINING PROGRAM
SUMMARY SHEET - PREDETERMINED APPROXIMATE PERFORMANCE TIMES

Drill guide block 2319 — Job name and number

Guide block 31 — Part name and number

7 Number of elements
✓ Workplace sketch attached
✓ Machine data sheet attach.
C F Schneider — Analysis by
6 Mar 1953 — Date
1 Page of
6 Pages

ALLOWANCES
A - Personal 30 Min/day
B - Irregular — Min/day

ALLOWANCE CALCULATIONS
1 - Reduction of A and B to percent
$\frac{30}{480-30} = 6.7$
C- Machine or process details

2 - Total allow.(A,B,C) 7 percent

Elem no.	Element title	Adj.time Min.	Allowed time Min.	Occurs per cycle	Prorated time Min.
1	Place block in fixture	.03245	.03472	1	.03472
2	Close lever and lock clamp	.01919	.02053	1	.02053
3		.05164	.0553		.0553
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

Note: For illustrative purposes this sheet has been completed as if the two elements in figure 5.39 completed the cycle. A reference to the data at the top will show there are actually 7 elements.

WORK UNIT Piece — TOTAL TIME PER CYCLE .0553 Min.

TOTAL TIME .922 hrs per 1000

ANTICIPATED PRODUCTION 1090 per Hr

FIG. **5.41** SUMMARY FORM FOR DEVELOPING STANDARD TIME FROM DATA OF FIG. 5.40.

are defining the performance standard as the average amount of time it has taken to produce a work unit in the past. This definition makes no assumption of improvement.

If we set a performance standard using an upper quartile, we are setting a performance standard that is something higher than average past performance. On this, I have two comments.

First, in the light of the purposes for which this standard is to be used, I feel that by using the upper quartile method we are automatically introducing errors in scheduling work, making budget estimates, and arriving at manpower allowances. My reasoning on this is that the mere fact that we are setting a high performance standard is not at all indicative that we will meet this standard in other than the long run sense. If we do not meet this standard, obviously we are going to require more manpower, money and equipment than the standard indicates, which will only complicate the budgeting, scheduling, and manpower activities.

Second, the upper quartile performance standard does not provide a uniform approach to the analysis in dif-

ferent work areas. In a work area where, due to the nature of the account and the work unit, the monthly fluctuations are very slight, the upper quartile will be very close to the average. In an account or work area where there is a great deal of dispersion in the data due to type of work being measured and the unit of measure, the upper quartile performance standard will be considerably higher than the average. Inasmuch as we have had a great deal of dispersion in our performance data in the past (which was only in part caused by fluctuations in productivity) we have no reason not to expect dispersion in the future simply because we have set a performance standard. The net result of using the upper quartile performance standard is that we are automatically setting the following criterion for how stiff the standard will be:

> The accounts or work areas with the greatest dispersion will have the stiffest standard.

This appears to me to be a particularly poor criterion for adjusting manpower.

The ultimate effect of the application of the upper quartile would be to eliminate personnel in a very unrealistic and undesirable manner based on a defenseless criterion.

No matter what statistical method is used to set a performance standard, it should be clear that no basis is afforded by which we can say an operation is good or bad—highly effective or not. Statistically, we can validly make statements as to the changes in the effectiveness; not as to the degree of effectiveness attained.

5.4.3.2 Recording the standard method and identifying the unit of work. The procedure indicated in Art. 5.4.1.2 can be followed; it needs no further detailing. However, since statistical standards are usually applied as a gross control to departments, operating units, or even whole establishments, numerous methods on different tasks, in varying numbers of repetitions, enter as time-consumers. The statistical standard is usually expressed as total time for end-product units of work. In some cases, this work-unit is not easy to identify. Take, for example, a shipping department for a job shop plant. The work required is a function of the number of items packed, the packing used, the weight and size of the items, and so on. Keeping records of what is actually done, in terms of these numerous variables, might require extensive study; in many cases, such data are not available from past records. A convenient work-unit is usually selected and its suitability is determined by comparing time (man-hours or man-days) consumed in the past and work-units produced. Statistical techniques such as curve-fitting and correlation are used to make this comparison.

5.4.3.3 Determining the relationship between time and work-units. Once a convenient and significant work-unit has been determined, time (man-hours or man-days) is stated as a function of the work-unit on the basis of the time statistic selected (see Art. 5.4.3.1). Reference to Art. 5.5 (Sources of error) will assist in the intelligent use of such standards.

5.5 Sources of error. Considerable difficulty in working with time standards can be avoided if it is realized that they involve an extremely sensitive area of human relations, and that they are far from absolute measures.

5.5.1 Stop-watch or camera time study. Even before the application of rating, several possible sources of error exist. The method observed may include deviations from that commonly used. Erroneous decisions may be made as to which observations are foreign elements, unallowable fumbles, or irregular elements. The sample of values observed may not be a random sample of the work required (by the usual product), or it may not be a truly random sample of performance. The application of statistical controls only increases the *probability* that the sample will be representative. Further, errors may be introduced by faulty reading of the stop watch, although these may be minimized by practice.

5.5.1.1 With common rating procedures. There is a considerable possibility that the time-study man will introduce error in establishing the mental concept

with which the observed performance is to be compared. Contributing factors may be the relations among the time-study department, operators, and foremen, or past experience, or simply the time-study man's mood. Also, there is no way of preventing these mental concepts from drifting slowly over a period of time. This drift may lead to a biased, rather than to a random, error. Further, error may arise in the comparison of concept and performance. Also, since the application of allowances usually requires judgment as to which category is applicable, further inconsistencies may be introduced in the standards.

5.5.1.2 Improved rating procedure. Although the improved procedure removes some of the sources of error common to conventional rating procedures, error may still be introduced when performance is compared with standard pace. Further error may be introduced by a poor element selection, even if the secondary adjustments are correctly applied. Also, the judgment of selecting a pace, to which to compare an observed performance, is replaced by the judgment of selecting the proper secondary adjustments to apply. However, this is a simpler type of judgment, and, although it is still a possible source of error, it represents a source of lower probability and magnitude; further, the resulting error will be random rather than biased. (If biased error appears, it may be removed by altering the table of secondary adjustments.) In addition, with the improved rating procedure the basis of judgment, both on pace comparison and secondary adjustments, remains constant over a period of time. And here again, the errors will be random rather than biased. The remarks made in 5.5.1.1 in respect to allowances apply equally to this method.

5.5.2 Synthesized standards. Methods of synthesizing standards tend to hide but not eliminate some of the sources of error.

5.5.2.1 Synthesized standards from standard elements. Since these standards are usually based on data from numerous time studies, random errors included in the original studies are usually reduced in magnitude, whereas biasing errors are carried on through. Additional errors may be introduced in new jobs by applying elemental standards to elements that are not identical, or by reassembling element times into a new pattern in which the elements affect each other even though no allowance is made for such an effect. Further, if variable elements have been plotted against a fortuitous variable, any new value extracted from such a curve may be in error. If the curve is extrapolated, the implied relationship may no longer hold and a spurious value will result. In addition, the so-called constant elements may not be constant; here is another possible source of error in application. The remarks made previously concerning allowances are also applicable.

5.5.2.2 Synthesized standards from basic motion times. In the first place, the original data may be of doubtful accuracy. Since the tables are based on average values, the data should be examined to determine possible inherent error. Secondly, the time for a therblig has been shown to be a function of:

a. Distance.
b. Complexity of action.
c. Amount of body involved.
d. Bimanualness involved.
e. Whether the use of the feet accompanies the action.
f. The eye-hand coordination required.
g. The sensory requirements.
h. The weight or resistance involved.
i. The preceding and following therbligs as well as the context of the whole pattern of the task.
j. The direction of the movement.
k. The place of the therblig in a motion pattern.
l. Possible interactions of two variables.
m. Several other variables as yet unidentified. (Even when the effects of variables *a* through *k* are extracted, considerable variation in observed data still exists.)

In several available systems of predetermining standards, the existence of

many of these variables is disregarded, although this is hardly a realistic procedure for eliminating them as sources of error. The system of data given in Art. 5.4.2.2 takes into account, to a degree, variables *a* through *i*. Error may still be introduced by an improper description of the task, a wrong classification of a therblig, a poor element grouping, and an incorrect selection of secondary adjustments. The remarks made in 5.5.1.1 concerning allowances are also applicable.

5.5.3 Statistical standards. Since statistical standards usually do not include a description of the work content (in terms of actions called for) of the work-unit, they lack this essential control and will be in error when the work content changes. Further, since they are based on past performances and provide no method of really appraising or evaluating these performances, they may be extremely inconsistent. Standards based on data from poor performances (poor because of equipment, work effort, worker ability, supervision, or intermittent activity) cannot be differentiated

FIG. **5.42** METHOD PROPOSAL SUMMARY FORM.

METHOD PROPOSAL SUMMARY

1. Date: ______ 1. Fewer people
2. Fewer steps
2. To: ______ 3. Less time on a step or steps
4. Less time in production
3. From: ______ 5. Less space
6. Less time for critical skills
4. Subject: ______ 7. Less time on critical equipment
8. Increased quality
______ 9. Less cost
______ 10. Less skill on step or steps
______ 11. Better control

Improvement will (insert proper numbers or describe if not classifiable.)

5. ______

6. If this proposal is approved it will be necessary to (summarize):

______

______

______

______

______

Attachments: (Insert number of sheets in proper boxes; follow with page nos. on lines.

7. [ ] ______ Cost of change estimate detail sheet
8. [ ] ______ Original charts
9. [ ] ______ Proposed charts, including summary and comparison
10. [ ] ______ Proposed equipment list and details of placement
11. [ ] ______ Jig, fixture, workplace or layout sketches or drawings
12. [ ] ______ Job instruction sheets as required by proposal
13. [ ] ______ Additional attachments list.

14. Financial aspects of change and evaluation of change (summary)

a. ______ estimated the annual volume.

b. ______ estimated the fixed cost of tools etc.

c. ______ Time new method would take to pay for itself.

d. ______ Original labor cost and hours, annual.

e. ______ Proposed labor cost and hours, estimated annual.

f. ______ Cost of change

g. ______ Net savings, annual (estimate)

PROCEDURE PROPOSAL SUMMARY

SPAS NO. 1

1 DATE ____________

2 TO ____________

3 FROM ____________

4 SUBJECT ____________

5 ☐ NEW PROCEDURE

6 ☐ IMPROVED PROCEDURE

7 ☐ IMPROVED FORMS

1 FEWER PEOPLE
2. FEWER STEPS
3 LESS TIME ON A STEP OR STEPS
4 LESS TIME TO COMPLETE PROCEDURE
5 LESS SPACE
6 LESS TIME FOR CRITICAL PERSONNEL
7 LESS TIME ON CRITICAL EQUIPMENT
8 INCREASED ACCURACY
9 CHEAPER PROCEDURE
10 LESS SKILL ON STEP OR STEPS
11 BETTER CONTROL

Improvement will (insert proper numbers or describe if not classifiable).

8 ____________

If this proposal is approved, it will be necessary to (summarize)

9 ____________

10 Financial aspects of change and evaluation of change (summarize)·

____

ATTACHMENTS (insert number of sheets in proper boxes; follow with page numbers on line)

11 ☐ ______ Original procedure chart

12 ☐ ______ Proposed procedure chart

13 ☐ ______ Proposed equipment list and details of placement

14 ☐ ______ Form designs and instructions for use, by forms

15 ☐ ______ Job instructions, by person

16 ☐ ______ Additional attachments list

ORDBC 43.1AR

FIG. **5.43** PROCEDURE ANALYSIS PROPOSAL SUMMARY FORM.

from standards based on good performances, nor can the reason for the differences be easily detected. Further, the larger the group, the more distantly the work-unit used may actually be related to work or effort input. Indeed, there is some question whether the word "standard" has the same significance as in the techniques of Arts. 5.4.1 and 5.4.2. However, if one recognizes these possible deficiencies and uses the statistical values as guides, they may be of considerable value.

5.5.4 Summary. All methods of deter-

WRITTEN STANDARD PRACTICE

PROCESS EARTHWORM TRACTOR PISTON RINGS

STEP NO.	NO. DEPT.	MACHINE	OPERATION	METHOD STD.	STD. TIME
1	9 Foundry	Class L	Mold	FM-7	.28 minute per unit of 4
2	9 Foundry	On Conveyor C-1	Pour mold	FM-8	.10 minute per tree of 40
3	9 Foundry	Bench and Hoist BH-3	Shake out	FM-9	.51 per tree of 40

From Mundel, *Motion and Time Study: Principles and Practice*, p. 394.

FIG. **5.44** WRITTEN STANDARD FOR PROCESS.

mining standards have at least several possible or probable sources of error. In using these methods, one should attempt, as far as possible, to control and reduce all controllable sources, while still recognizing their nature and the existence of other sources. Also, it should be recognized that the values produced are only approximations of the concept embodied in the statement of standard.

FIG. **5.45** SAMPLE TIME STANDARD FORM FOR RATE BOOK.

ACE VALVE Co.–WORK STANDARD

DEPT
OPERATION
PART
RATE

SET BY	APPROV	STANDARD TIME (hours/pc.)	PIECES PER HOUR	METHOD NO.	DATE

From Mundel, *Motion and Time Study: Principles and Practice*, p. 399.

WRITTEN STANDARD PRACTICE
The Perfect Circle Co.

SECOND INSPECTION

No. SI 14
Issue 2
Sheet 1 of 3
3-6-44

OPERATION: Gap Gage Earthworm Tractor 5 3/4" Rings

EQUIPMENT

1 Sizer Ring Gage	1 V Trough
3 Set Feeler Gages	1 V Trough (non-sectioned)

REQUIREMENTS

Operator will wear gloves when handling rings.

All pans of rings will be lifted by service men.

Pan ticket will remain in pocket on side of pan, except when being read by operator.

Operation will be performed by checker.

Ring gages will be checked at the beginning of each shift by a checker.

A ticket showing ring gage size, variation number, feeler gage number, operator's clock number and date will be filled out when ring gage is checked and will be kept with gage while it is in use.

Feeler gages will be kept at the Foreman's desk and will be returned to desk at end of working period.

SPECIFICATIONS

Gage Size: 5.747 Gap Clearance: .011 - .021

Rings will be gaged on a percentage basis. Operator will gage every 8th ring, beginning with bottom ring and ending with top.

If any ring is found out of limits, operator will check 8 rings above and 8 rings below place from which reject was removed until all rings not within limits have been rejected.

SECURE RINGS

1. HAVE SERVICE MAN PLACE ENTIRE TEST of rings at back of bench in a horizontal position.

CHECK SET-UP

2. CHECK PAN TICKET to see that previous operation has been completed. Check number of rings in pan against count shown on ticket. (Count remnant row and add to number in full rows). If counts do not agree, have floor clerk make necessary corrections.

From Mundel, *Motion and Time Study: Principles and Practice*, p. 395. Reproduced by courtesy of D. C. Parsons, Mfg. Mngr., Perfect Circle Co.

FIG. 5.46a WRITTEN STANDARD PRACTICE FOR OPERATION

6. MOTION AND TIME STUDY REPORTS

6.1 TYPES AND USES

If adequate use is to be made of the data developed through motion and time study, adequate reports should be submitted in connection with: (a) each project undertaken, and (b) total activity in these functional areas. The individual project reports normally form a basis for acceptance or rejection. Adequate reports of total activity serve as: (a) a continual reminder of what can be

SECOND INSPECTION | WRITTEN STANDARD PRACTICE The Perfect Circle Co. | No. SI 14 Issue 2 Sheet 2 of 3 3-6-44

OPERATION: Gap Gage Earthworm Tractor 5 3/4" Rings

GAGE RINGS

3. REMOVE EVERY 5TH RING from first row of pan, beginning with bottom ring and ending with top.

4. PLACE RINGS ON BENCH in front of first row with gaps toward operator in the order removed from pan.

5. REMOVE SPECIFIED NUMBER OF RINGS from remaining two rows in the manner described in Steps #3 and #4.

6. MOVE GAGE to a position at left end of first pan.

7. PICK UP FEELERS AND HOLD them between thumb and index finger while gaging rings. (When placing ring in gage or removing ring from gage, hold feelers in palm of hand.)

8 PICK UP ONE RING from first stack on right approximately 1" on right of gap with thumb and index finger of right hand.

9. BRING RING TO A POSITION OVER GAGE.

10. GRASP RING on left of gap with left index finger and thumb, placing middle fingers on top of ring and thumbs on face and corners about ½" on either side of gap.

11. TILT RING SLIGHTLY AND SLIP BACK OF RING INTO GAGE.

12. INSERT REST OF RING INTO GAGE by squeezing thumbs together toward gap.

13. ROLL THUMBS OFF RING to release points slowly. Do not flip points into gage. Be sure back of rings is pressed firmly into gage.

14. TEST GAP by placing Go feeler between points, starting at inside diameter and bringing feeler toward operator through gap. Go feeler should pass between points freely. If feeler passes through gap with a slight drag, ring should be rejected.

15. PLACE NO GO FEELER BETWEEN POINTS, starting at inside diameter and bringing feeler toward operator through gap. The feeler should either refuse to pass or should fit very tightly. Do not force feeler between the points.

16. REMOVE RING FROM GAGE by closing gap with thumb and index fingers of each hand and lifting ring. Do not flip points out of gage.

17. PLACE IN NON-SECTIONED TROUGH ON LEFT OF GAGE AND AT SAME TIME REPEAT STEP #8, if ring is within limits.

    a. If ring is not within limits, place in sectioned trough on left of gage in section marked for that type reject.

From Mundel, *Motion and Time Study: Principles and Practice*, p. 396. Reproduced by courtesy of D. C. Parsons, Mfg. Mngr., Perfect Circle Co.

FIG. **5.46b** WRITTEN STANDARD PRACTICE FOR OPERATION, CONTINUED. (SPACE DOES NOT PERMIT REPRODUCING THE REST OF THIS.)

```
METHODS IMPROVEMENT AUDIT

_______________ INSTALLATION
_______________ DEPARTMENT
_______________ DATE ENDING, PERIOD COVERED

I  METHODS PROPOSALS
   a.__________Total proposals of method changes made to date.
   b.__________Cumulative changes proposed prior to period and awaiting action.
   c.__________Number of method changes proposed in period.
   d.          Number of changes acted upon.
     __________  1. From prior periods.
                 2. From reporting period.
   e.__________Number of changes awaiting action (#2  #3  #4).
   f.          Number of changes approved and approval %; Approved    X 100.
                 1. For prior period.                     Acted upon
     __________  2. For reporting period.
   g.__________1. Total savings of accepted proposals from Method Proposal
                   Summary Sheets cumulative for a year.
     __________2  Average increase in production for reporting period.
     __________3. List highest three.
     __________
     __________

II TALLY OF CATEGORIES OF SAVINGS ACCEPTED DURING PERIOD
   a.__________Fewer people.
   b.__________Fewer steps.
   c.__________Less time on a step or steps.
   d.__________Less time in production.
   e.__________Less space.
   f.__________Less time for critical skills.
   g.__________Less time on critical equipment.
   h.__________Increased quality.
   i.__________Less cost.
   j.__________Less skill on step or steps.
   k.__________Better control.
   l.__________Miscellaneous.

III NUMBER OF SOP'S PREPARED FOR SHOP METHODS
   a.__________Revised.
   b.__________New.

IV SUGGESTION PROGRAM
   a.__________Number of suggestions submitted for period and cumulative.
   b.__________Percent of employees submitting suggestions.
   c.__________Percent and number of ideas approved.
   d.__________Number of suggestions held over one month.
   e.__________Cost savings resulting from suggestion program:
     __________  From reporting period
     __________  Cumulative yearly.
   f.__________Cost of administering program.

V  TRAINING PROGRAMS
   a.__________Number of supervisors trained in Methods Improvement:
     __________  1. In reporting period.
     __________  2. Total.
   b.__________Number of employees trained in Methods Improvement:
     __________  1. In reporting period.
     __________  2. Total.
```

FIG. **5.47** METHOD IMPROVEMENT AUDIT FORM. (DEVELOPED BY DR. I. LAZARUS, ARMY ORDNANCE MANAGEMENT ENGINEERING TRAINING PROGRAM.)

done, (b) a basis for programming future activity, and (c) a basis for evaluating the worth of the activity.

6.2 PROJECT REPORTS

Project reports may be submitted in the form of a method proposal, a procedure proposal, or a work standard.

6.2.1 Method proposal. A form suitable for summarizing the content of a method proposal is shown in Fig. 5.42. This would satisfactorily serve as: (a) a letter of transmittal, (b) a summary sheet, or (c) a source for summarizing the information into a periodic report.

6.2.2 Procedure proposal. A form suitable for summarizing the results of a procedure proposal is shown in Fig.

PROCEDURE ANALYSIS ACTIVITY AUDIT SHEET

____________________INSTALLATION

____________________DEPARTMENT

____________________DATE ENDING, PERIOD COVERED

I ACTIVITY

a. __________Total number of man hours spent in procedure and forms design studies during report period.
b. __________Reduction in man hours of work load per month as result of procedure and forms design changes during report period.
c. __________Cumulative savings in man hours.

II PROCEDURE STUDIES

a. __________Approximate number of procedures in installation.
b. __________Total number of procedures recorded graphically at end of last report period.
c. __________Number of procedures recorded graphically during this report period.
d. __________Total number of procedures recorded graphically at end of this report period.
e. __________Number of procedures proposals submitted during report period.
f. __________Number of procedure proposals accepted during report period.

III FORMS DESIGN

a. __________Total number of forms in use at end of last report period.
b. __________New forms created not replacing old forms.
c. __________Number of forms combined.
d. __________Number of forms eliminated.
e. __________Net change in number of forms in use.
f. __________Total number of forms in use at end of present report period.
g. __________Number of forms simplified.

FIG. 5.48 PROCEDURE ANALYSIS AUDIT FORM. (DEVELOPED BY MR. J. MOQUIN, ARMY ORDNANCE MANAGEMENT ENGINEERING TRAINING PROGRAM.)

5.43. This form serves the same three purposes served by Fig. 5.42.

6.2.3 Work standard. The standards for a process may be reported in the form shown in Fig. 5.44. The standards for an operation may be reported on the form shown in Fig. 5.45. Either form would be backed up by time studies and operator instruction sheets. Part of an operator instruction sheet is shown in Fig. 5.46.

6.3 ACTIVITY REPORTS

Separate activity reports may be submitted for each of five functional areas:

a. Methods improvement.
b. Procedure analysis.
c. Labor standards development.
d. Training (work simplification, etc.).
e. Suggestion plan operation.

Only the first three of these are de-

LABOR STANDARD DEVELOPMENT AND APPLICATION AUDIT

______________ INSTALLATION

______________ DEPARTMENT

______________ DATE ENDING, PERIOD COVERED

I LABOR STANDARD DEVELOPMENT

a. ______ Total number labor standards, present.
b. ______ Total number labor standards, last report.
c. ______ Number increase over last report.
d. ______ Total number labor standards revised; method changes.
e. ______ Total number labor standards revised; other reasons.

II STANDARD HOURS COVERAGE

a. ______ Total elapsed man hours during report period covered by labor standards.
b. ______ Total daywork man hours during report period.
c. ______ Total elapsed man hours during report period.
d. ______ Percentage of hours covered by labor standards.
e. ______ Total number of operations performed during report period covered by labor standards.
f. ______ Total number of operations performed during report period not covered by labor standards.
g. ______ Percentage of operations performed covered by labor standards.

III PRODUCTIVITY ANALYSIS

a. ______ Total standard man hours produced on work covered by standards.
b. ______ Total elapsed man hours on work covered by standards.
c. ______ Percentage productivity.

IV DELAY HOURS ANALYSIS

a. ______ Total machine downtime delay man hours.
b. ______ Percentage of machine downtime to total elapsed man hours.
c. ______ Total set-up delay man hours.
d. ______ Percentage of set-up time to total elapsed man hours.
e. ______ Total miscellaneous delay man hours.
f. ______ Percentage of miscellaneous delay to total elapsed man hours.
g. ______ Total delay man hours.
h. ______ Percentage total delay to total elapsed man hours.

FIG. 5.49 WORK MEASUREMENT AUDIT FORM. (DEVELOPED BY MR. C. SCHNEIDER, ARMY ORDNANCE MANAGEMENT ENGINEERING TRAINING PROGRAM.)

scribed in this section. Such reports are often referred to as "periodic audits of the performance of the function."

6.3.1 Methods improvement. A form suitable for periodic reports on the performance of this function, as developed by Dr. I. Lazarus of the Army Ordnance Management Engineering Training Program, is shown in Fig. 5.47.

6.3.2 Procedure analysis. A form suitable for periodic reports on the performance of this function, as developed by Mr. J. Moquin of the Army Ordnance Management Engineering Training Program, is shown in Fig. 5.48.

6.3.3 Labor standards development. A form suitable for periodic reports on the performance of this function, as developed by Mr. C. Schneider of the Army Ordnance Management Engineering Training Program, is shown in Fig. 5.49.

7. MOTION AND TIME STUDY POLICIES

7.1 DEFINITION

Policies are statements of the procedures and aims to be followed by an organization in meeting recurring situations.

7.2 AREAS TO BE COVERED

If routine motion and time study work is to be effective, the controlling policies should state the aims and procedures for at least the following seven items.

a. Who shall determine the standard method?
b. How will the standard method be put into practice?
c. What does standard time represent?
d. Who shall determine the standard time and how will it be determined?
e. Under what conditions may a standard time be changed?
f. How will production and hours expended be reported?
g. How often and through what channels will reports on the performance of the motion and time study functions be reported?

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Lawrance F. Bell is a well-known West-coast industrial engineer. He was raised in Los Angeles, attended the University of California at Los Angeles and Stanford University, and has been engaged in industrial engineering practice in California and Arizona since 1942. His degrees are an A.B. in Mechanical Engineering and an M.S. degree in Engineering Statistics, both from Stanford University. He is a member of Tau Beta Pi and a registered professional engineer.

After three years with the Aluminum Company of America, Mr. Bell joined the Los Angeles staff of Anderson-Nichols and Company, management engineers. He was a member of the industrial engineering faculty at Stanford University from 1947 until 1952, when he accepted the position of Procedures Engineer with Varian Associates, klystron manufacturers. He is now Industrial Engineer for the Metalbestos Division of the William Wallace Company.

Motion and time study, production control, cost accounting, production engineering, quality control and engineering economy are the closely related fields in which Mr. Bell has had wide experience. Through the combination of industrial and educational work in these areas, he acquired an insight into the basic problems of system and procedure improvement that led him to develop the practical philosophy embodied in the following section.

Mr. Bell is a member of the Systems and Procedures Association of America, American Society of Mechanical Engineers, American Society for Quality Control, and American Institute of Industrial Engineers. His publications include articles in national magazines, research papers, and reports. While at Stanford he made important contributions to the development of industrial engineering courses in time and motion study and in production engineering. He also served as an engineering consultant to the Statistics Department and to various industrial concerns.

SECTION 6 Factory Systems and Procedures

Lawrance F. Bell

This section is for those interested in improving the effectiveness and reducing the cost of systems and procedures. It is essentially a summary of ideas well known to professional system analysts. Some new concepts and points of view are introduced to provide a better understanding of problems of system design and how they can best be solved. The general plan is to describe the nature of procedures and systems and indicate why they are necessary, to point out what makes good systems good and bad systems bad, to present some important ideas and principles and develop some helpful rules for improvement, and to provide some useful information about systems devices and techniques and the design and forms of reports. The ideas and information presented are slanted toward the problems of manufacturing companies, but are applicable to any organization. Special emphasis is given to systems for materials control and purchasing, and production planning and control. Accounting systems are treated only indirectly, as part of the over-all pattern of interrelated systems.

1. SYSTEM, PROCEDURE, AND METHOD

1.1 ADMINISTRATIVE PLANS

The essence of any organization is people working together to achieve common goals. For the over-all effort to be successful, decisions and actions must be coordinated among individuals and between groups; they must be consistent, and, on the average, they must yield satisfactory results at a reasonable cost. To accomplish this, a structure of administrative plans is necessary to give direction to individual activity and to serve as the basis for control.*

Procedures are one type of plans necessary for effective and economical administration. To understand the nature of procedures and why they are necessary, it is helpful to analyze the total complex of administrative plans of which they are an essential part.

Newman divides plans into two general categories: those which are stated in terms of results to be achieved (goals), and those which are stated in terms of actions (operating plans).† Under *goals,* Newman includes general objectives, deadlines, specifications, quotas, and all types of standards for operating achievement. He divides operating plans into *single-use* plans, which "lay out a course of action to fit a specific situation and are used up when the goal is reached," and *standing plans*, which "are designed to be used over and over again." Organization, policies, procedures, and standard methods fall in the latter category of standing administrative plans.

* See B. E. Goetz, *Management Planning and Control* (New York: McGraw-Hill Book Company, Inc., 1949), Chapter 4.

† W. H. Newman, *Administrative Action* (New York: Prentice-Hall, Inc., 1951), Chapters 2 and 3.

1.2 PROCEDURES

1.2.1 Definition. A *procedure* is a predetermined course of action. Procedures are standing plans for people to follow in carrying out repetitive administrative tasks in a systematic way. They are a translation of general plans and policies into standard patterns of decision and action. They establish who shall do what, and when, and in what sequence.

Some examples of procedures are the sequences of action required to:

Initiate purchase of a special item.

Make a bank deposit.

Effect a drawing or specification change.

Verify and pay an invoice.

Establish a new job description.

Receive an incoming shipment.

Acquire an additional employee.

Procedures are not always well planned or well designed. They often "just grow" piecemeal fashion, as a result of pressures for speed, accuracy, self-protection, control, and simplified supervision. This is a process of evolution, by trial and error, in which loopholes are plugged and deficiencies are corrected as they become problems. Such procedures become standard practice through usage, general acceptance, and subsequent enforcement.

Although procedures are managerial plans, they are seldom actually initiated and developed by executive direction. Typically, they are originated in the middle and lower levels of the organization by the people directly involved in routine activities and their immediate supervisors.

A procedure is not necessarily written; it may not be recorded either in outline nor in detail. Customary practice, which has not been recorded or even approved, is just as much *procedure* as well-planned, written standard instruction.

Procedures do not always involve paperwork. Forms and reports are merely devices which are commonly used to facilitate routine handling of information. In the office functions of most organizations, paperwork is so commonplace and evident that it is often difficult to discriminate between this physical aspect of office activity and the underlying plans and sequences.

Procedures are necessary for all repetitive functions, not only for those carried on in an office. Office procedures are perhaps more evident, but hardly more important or numerous than those of the shop, warehouse, laboratory, and field.

1.2.2 Procedures are necessary. When a certain situation requiring decision or action recurs periodically, or is duplicated for each occurrence of a commonplace event, it is necessary that many of the questions shall be answered once and for all, and not be re-evaluated each time. There are many reasons for this. In the first place, no human being could be induced to ignore his previous experience and treat each recurrence of the same situation as an entirely new and foreign problem. Left to his own devices, he would soon revert to standardized decisions and actions, concentrating his attention only on the variables and differences. This is one reason why procedures come into existence even in the face of supervisory indifference.

A more business-like reason for procedures is that it is cheaper to handle repetitive activities by routine standard practice. Work can be delegated to people of less general training and more specialized skill. The individual cases can be processed much more rapidly at a lower unit cost. But perhaps more important is the economy of supervisory and executive time. Newman points this out as follows: "If an administrator had to develop a complete set of plans each time he wished to initiate action or there was a change in operating conditions, he would be faced with an impossible task. . . . Instead, for every enterprise there will be found a wide variety of standing plans which are followed every time a given situation is encountered. . . . Such standing plans greatly simplify the task of the administrator. They establish a pattern of action that the planner assumes as 'normal,' and he can then concentrate his attention on the changes

he wishes to make in this customary pattern for abnormal circumstances." *

Procedures are also necessary to insure consistency among decisions and actions of the same type made at different times. This is particularly important in matters affecting the external relationships of the company with customers, government agencies, financial institutions, and investors. Consistency of decision and action is also important for internal control, continuity of information, and coordination.

Information for making decisions and plans and guiding actions must be reliable. This means that it must be accurate enough for the purpose, consistent with prior and related information, and properly identified as to source and meaning. Standard procedures are necessary for collecting, recording, transmitting, and storing this information. If they are well designed, the information will be reliable.

By providing plans of action for all anticipated eventualities, procedures forestall confusion, random action, and counteracting effort, and therefore help to expedite each individual case through the necessary administrative processes. Thus, speed is another benefit, provided the path to the objective is not littered with unnecessary procedure or overgrown with poor work methods.

Perhaps the most important contribution of procedures toward effective administration is in providing adequate assurance that the things which need to be done will be done at the proper time in the proper way. Many procedures are devised for this reason alone. The problem of improving this assurance is treated in Art. 8.

Procedures have disadvantages as well as advantages. Standardization of decisions and actions tends to reduce the apparent necessity for thinking. There is always the danger that a procedure will be applied to a situation for which it is not appropriate, or that it will be modified in some detail and produce chaos or serious loss to the company through some disregarded ramification. Standard procedures can also yield costly results when a supervisor or executive fails to realize all the procedural consequences of a simple request or order. In other words, to be effective, procedures need to be well understood by the people who are following them, and also by their superiors.

One inherent disadvantage of procedures is that they cost money to develop, install, and maintain; this cost must be recoverable through repeated usage. It is also important to note that they can easily cost more to operate than the benefits they produce if they are poorly designed. They tend to be self-generating and self-perpetuating, and a great deal of money can be spent in following procedures which are useless, misleading, or so far behind in operation as to be completely irrelevant.

1.2.3 Distinction between procedure and method.* A procedure is a plan for an administrative process. It establishes the sequence, timing, and coordination of operations, and specifies where each shall be done and by whom. The term *method* is used to refer to *how* the work is accomplished. *Procedure*, then, means "method" only in the broad sense of process design, and *method* means the detailed work method employed in any one operation.

1.2.4 Relation between procedure and policy. Any organization has a structure of policies which define and guide the activities of the company. These policies encompass all the standing decisions which establish the nature of the company, and its institutional personality, attitudes, and behavior. They represent the body of internal law

* Newman, *Administrative Action*, p. 40.

* No two authors or procedure analysts seem to agree about the exact meaning of the words *method* and *procedure*, and many use these terms interchangeably. However, it is helpful to attach different meaning to these words in any discussion of systems design. The above definition of *method* is adapted from Richard F. Neuschel, *Streamlining Business Procedures* (New York: McGraw-Hill Book Company, Inc., 1950), pp. 9-10.

governing the conduct of the people within the company. They establish the rules for individual action, and the basic patterns for decision.

Procedures are operational plans for repetitive functions. As such, they must be consistent with all pertinent policy. They also must be supplemented by policies for guiding decisions and shaping plans. And they must rely on policies for authority and enforcement.

Policies establish general direction for action and patterns for decision. Procedures fix the specific courses to be followed. Policies form a platform of decisions on which procedures are built. In fact, satisfactory and durable procedures cannot be established without first closing any gaps in policy which may exist.

1.2.5 Relation between procedures and organization. Procedures and organization are two intimately associated forms of managerial planning. Two factors are inherent in both: the assignment of responsibilities, and the problem of coordination. In general, organization plans are broader and more basic than procedural plans. Conversely, procedural plans are, or should be, subsidiary to organizational plans.

From one point of view, the development of procedures for routine activity is merely an extension of organization planning into the details of who should do what, and the questions of timing, sequence, and method. As a practical matter, organization planning does not go into details except in the matter of who shall report to whom. With respect to the assignment of responsibilities, there is no clear line where organizational planning leaves off and procedural planning takes up. Organization plans, in the form of organization charts and responsibility descriptions, ordinarily define the general areas of responsibility delegated to groups and individuals. Procedures establish specific duties (functional responsibilities) for individuals. Clearly, they need to be consistent with organization plans.

Procedures play a more prominent role in the coordination of activities between individuals and departments. They establish formal lines of communication and cooperative effort, which are the connecting linkages between organizational units. Whereas the organization plan groups and aligns functions vertically, procedures operate horizontally across the lines of organization as well as up and down along the lines of organization.

Any organization plan arbitrarily divides the employees into groups with special interests, loyalties, responsibilities, and authorities. But these individual organization units cannot operate independently; each must contribute its special part to accomplishing company tasks. For example, the receipt of a customer's order for a stock item must touch off a chain of actions running through several departments to effect the release, packing, shipping, and billing of the item. Subsequent actions must include recording the transaction, obtaining and handling the customer's payment, and initiating replacement of the item in stock. Procedures are the means of integrating the efforts of different organizational units in carrying out such routine functions. They are the mechanism for interdepartmental coordination.

1.2.6 Procedures have structure. Procedures form complex networks of interrelated plans of action. Few procedures are truly independent. The major ones are always interwoven into a web which spreads across departmental lines and physical boundaries. For example, a procedure for receiving purchased materials is merely a segment of the materials requisitioning-procuring-receiving-storing-issuing cycle. This cycle of actions is, of course, supported and made possible by prior sequences in the technical, planning, and control departments. In turn, this cycle activates or interlocks with other procedures branching through accounting, production, and so on, and those which feed back information to the technical, planning, and control departments.

The structure of procedures is, by analogy, like the nation's network of railroads. There are main lines and lesser

lines, joint lines and separate lines, junctions and sidings, depots and switching yards. The traffic flows between systems and between areas; activity at any one point may ultimately run through countless other points.

Procedures differ in functional importance. The more essential ones necessitate and control the many minor ones. At the same time, some apparently minor procedures are multi-purpose—they serve more than one main-line procedure. It is often difficult to predict all the ramifications of a change in a procedure, or to recognize possibilities for simplification by combining or integrating related procedures. This requires a company-wide point of view, and knowledge of the activities and requirements of all departments.

1.3 SYSTEMS

A *system* is an assemblage of people, devices, and plans for performing an administrative function. All these components are necessary—the *people* to make decisions and take action, the *devices* for them to work with, and the *plans* to guide them and coordinate their efforts.*

No administrative system can operate without human intelligence and human hands. The number of people involved may be one or many. Individually, they may be engaged full-time or part-time. They may be responsible for certain tasks continuously or intermittently—for all cases, or only in certain circumstances. One ever-present problem in systems design is that frequently the "person" responsible for a necessary action is not a specific individual, but one or all of a group of people. In these situations, the system must accommodate many individuals acting in the same capacity at different times or places.

The core of any system is a network of standard procedures reinforced with standard methods. This procedural structure must be built on a foundation of policies and shaped to fit the organization pattern. It is the framework of the system. It fixes the functions and purposes, and it provides the necessary direction and coordination for effective operation.

The devices and forms employed in the system may be a major determinant of its cost and effectiveness. This is particularly true where a large number of items of information must be handled, or where speed and accuracy are important. In such cases, the choice of equipment may control many decisions concerning the forms, methods, and procedures, and may effectively establish the general plan of the system. In other cases, the devices and forms may have a heavy influence on the functional soundness of the system. Examples of this are common in planning and control activities.

Dynamically, a system may be viewed in terms of *information* flowing, and being recorded, processed, summarized, used, stored, and discarded. Information is the life blood of an administrative system. It is necessary for making decisions and plans, for initiating and directing action, and for comparing results against plans. Information may also be an objective in itself—for example, the information necessary for external reports required by law.

A system may be analyzed or described in various ways:

In terms of its scope and purposes.

In terms of the responsibilities of the departments involved.

In terms of what the people do—procedures and methods.

In terms of the forms and their use.

In terms of the information with which it operates.

In terms of the equipment it employs.

Ordinarily, some combination of these factors must be described to give an

* Some authors define a system as merely a set of related procedures, the distinction between a procedure and a system being only a matter of degree of complexity. It is considerably more helpful to view a system as a fully equipped and staffed administrative mechanism.

adequate picture of the system as a whole. The most practical combination for most uses is a statement of scope and purposes, a summary of departmental responsibilities, and a description of the procedures and methods.

1.4 EXAMPLES OF SIMPLE SYSTEMS

The following examples of factory systems were chosen because they are relatively simple in scope and purpose, and relatively independent of other systems. Although they are not typical in complexity or importance, they serve well to illustrate many useful ideas about systems and procedures.

1.4.1 Example I—a tool supply system. This system was designed for a small company of about 250 people. It was aimed at correcting many problems associated with the cutting tools used on 33 production lathes of various types. These machines were operated by 50 to 55 men, day and swing shifts combined. Prior to the installation of this system, each man maintained his own supply of tool bits at the machine to which he was ordinarily assigned. He had the option of sharpening his own tools or taking them to the tool grinder to have them sharpened to his specifications. New tool shanks and tips, and ready-made purchased tools, were available at the tool crib on verbal request. The day shift tool grinder made periodic trips through the shop (and to the scrap bins) collecting worn, broken, and obsolete tools for salvage. The major changes necessitated by the new system included placing the inventory of lathe tool bits under tool crib control, and transferring the responsibility for tool bit design and sharpening from the machine operators to the tool grinder in the maintenance department.

The following description was condensed from the original report presenting the proposed new system for review and approval.

I. *Functions and Scope:*

A. Providing cutting tools for the production lathes.

B. Sharpening and replacing dull and broken tools.

II. *Purposes:*

A. To reduce production costs: setup time, tool change frequency and time, wait-for-tool time, operation time (feed and speed), and amount of scrap and rework.

B. To minimize and control the costs of tool grinding, tool materials, and tool inventories.

III. *General Plan:*

A. Classify all tool bits:

1. Standard tools—those to be sharpened in the tool room (including all carbide-tipped and form tools).

2. Stock tools—those to be sharpened by machine operators (mainly carbon-steel tools of simple design).

B. Establish specifications and identification numbers for all standard tool bits.

C. Standard tools:

1. Place under tool crib control.

2. Sharpen in tool room.

3. Provide for foreman's authorization of temporary and experimental tools.

D. Stock tools:

1. Place under inventory control in tool crib.

2. Provide for issuing and replacing.

IV. *Equipment:*

Tool bit rack and "At Grinder" checks (see Fig. 6.1).

V. *Forms:*

Tool tag (see Fig. 6.1), tool requisition slip, standard tool record sheet.

VI. *Procedures:*

A. Machine operator:

1. To obtain a standard tool, write tool tag and exchange for tool at tool crib.

2. When tool dull or broken, exchange for sharp tool (no tag required).

3. When job completed, return tool to crib. Receive and destroy tool tag.

B. Tool crib attendant:

1. Issue sharp tool on receipt of tool tag. Hang tag on tool rack.

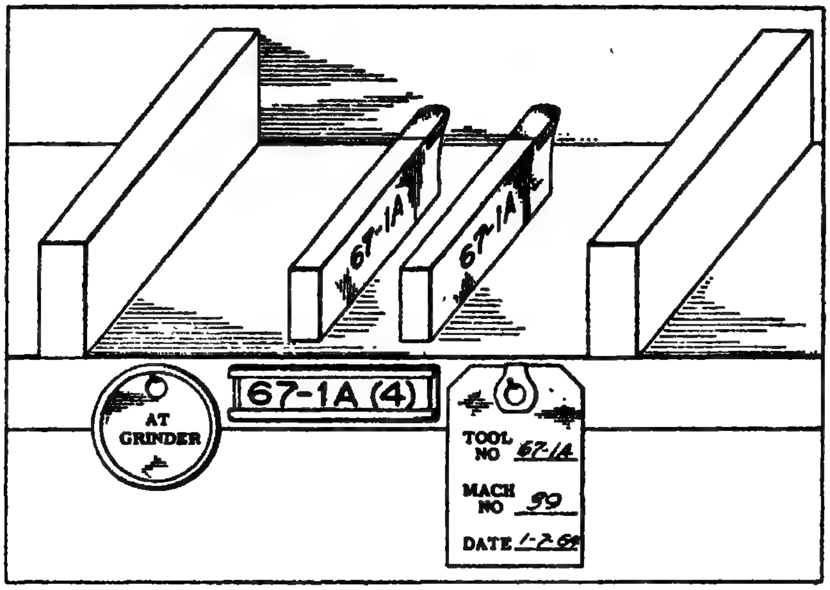


FIG. 6.1 SECTION OF TOOL STORAGE RACK USED IN THE TOOL SUPPLY SYSTEM DESCRIBED IN EXAMPLE I. LABEL INSERTED IN HOLDER ON FACE OF SHELF CARRIES IDENTIFICATION NUMBER AND STOCK QUANTITY OF TOOL. (THERE ARE FOUR COPIES OF TOOL NUMBER 67-1A: TWO IN THE RACK, ONE AT MACHINE NUMBER 39, AND ONE AT THE TOOL ROOM BEING RE-SHARPENED.)

2. Issue sharp tool in exchange for dull or broken tool. Hang "At Grinder" check on tool rack and place dull tool in tote pan.

Note: If all copies are out when a tool is requested, notify shift foreman immediately.

3. When tool turned in from shop, place in tote pan. Replace tool tag with "At Grinder" check and return tag to operator.

4. When sharp (or replacement) tool returned by tool grinder, put tool in rack and remove check.

Note: All copies of each tool must be accounted for at all times. The number in the rack plus the number of checks and tags on the hooks should always equal the stock quantity for that tool as shown on the bin label. Notify shift foreman of any discrepancy.

C. Tool grinder:

1. Pick up dull tools at tool crib daily. Sharpen (or replace) per specification sheet, and return to crib within 24 hours.

2. Requisition tool steel from crib as necessary. Salvage and re-use shanks of worn-out and broken tools whenever practical.

3. Make special tools, and additional copies of standard tools, per tool requisition slips signed by machine shop shift foreman.

4. Assign tool numbers. Develop and record specifications for standard tools.

5. Maintain record of usage and replacement. Eliminate obsolete tools with approval of machine shop foreman.

Additional procedures which are part of this system, but are not described here, provide for (1) establishing the specifications, identification number, and stock quantity for each standard tool. (2) Increasing the stock quantity of a standard tool. (3) Authorizing and controlling experimental and temporary tools. (4) Issuing and controlling stock tools. (5) Issuing and re-ordering tool materials.

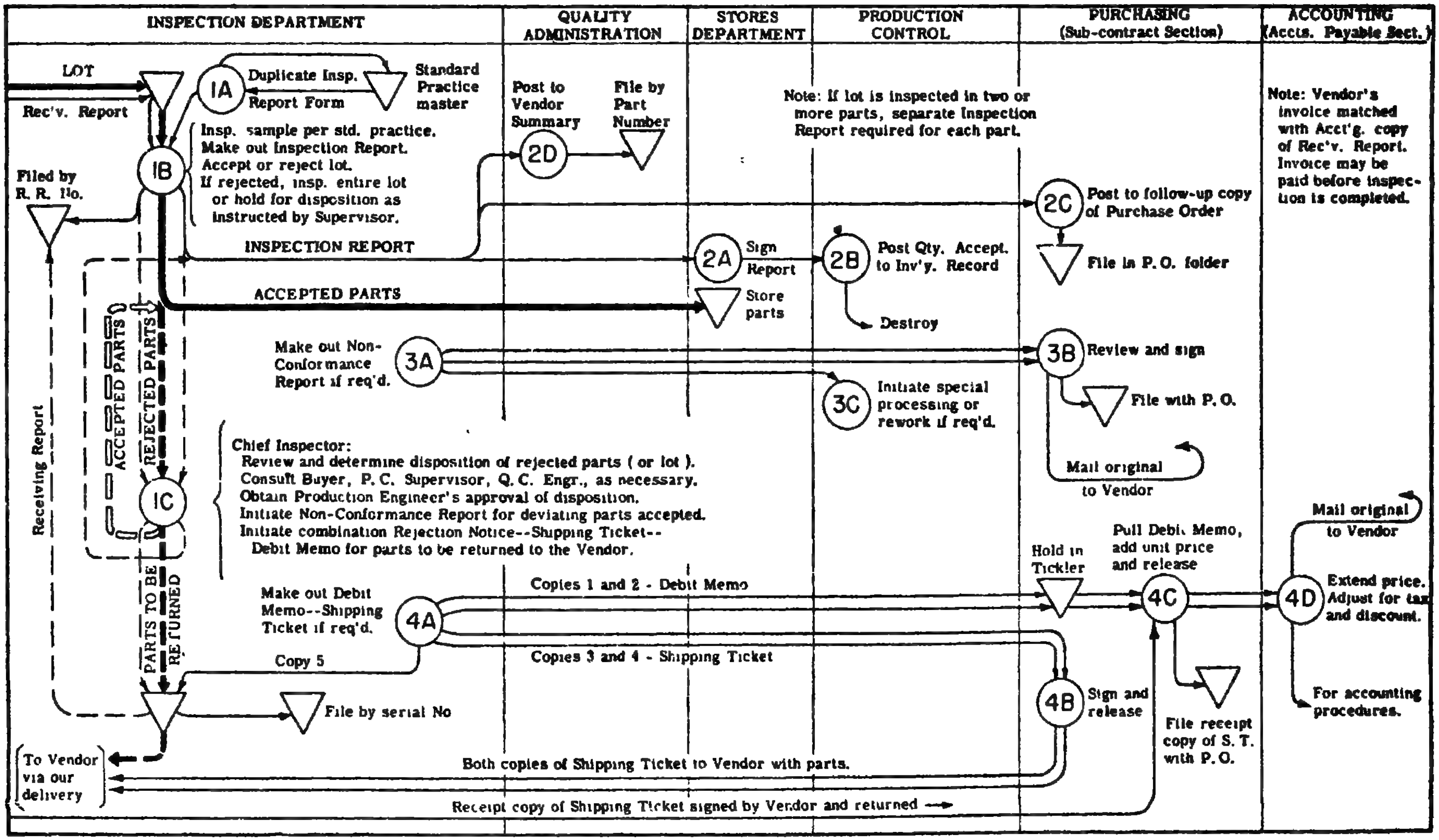


FIG. 6.2 DIAGRAM OF AN INCOMING PARTS INSPECTION SYSTEM.

Quite properly, this system requires very little paperwork of the skilled workers and foremen. The only writing required for a complete use-sharpen-store cycle of a tool, is in making out the tool tag (three items of information) and noting the date and a tally mark on the tool record sheet. A tool requisition slip is required only if a new tool, or an additional copy of an existing tool, is to be made. Of course, additional paperwork is required in the adjacent systems concerned with purchasing tool materials, accounting for tool costs, and planning and specifying operation methods.

One unique aspect of this system is that it affects directly people in only two departments—the machine shop (lathe production centers and tool crib) and the maintenance department (tool room). For this reason, it is relatively independent and easy to isolate for the purposes of analysis and description.

1.4.2 Example II—an incoming parts inspection system. The system diagrammed in Fig. 6.2 is adapted from a medium-sized company producing many varieties of a technically difficult product. The dimensions, finish, and physical and chemical characteristics of the component parts have an important effect on the quality of the end product. Consequently, all parts and subassemblies received from subcontractors are subjected to a rather thorough physical inspection before being placed in stock.

Considerable time is required to inspect adequately an incoming lot, making it necessary to pay vendors' invoices on the basis of parts received rather than parts accepted. If any unsatisfactory parts are returned, they are charged back to the vendor by means of a debit memo originated in the inspection department.

For each part, the quality characteristics to be inspected, the methods of inspection, and the amount of inspection are pre-planned. This information is recorded on a duplicator master from which triplicate sets of the inspection report form are run off as needed.

The copy of the receiving report which arrives with each lot is used in inspection to identify the lot and to serve as a job routing and record sheet.

Operationally, this system may be broken down into four procedures, the purposes of which are as follows:

1. Inspecting each lot and determining the disposition of rejected parts.
2. Transferring accepted parts to stock, and distributing and using the inspection report.
3. Notifying the vendor and production control of nonconforming parts accepted.
4. Returning unsatisfactory parts and back-charging the vendor.

The first two of these procedures apply to each lot, with variations depending on the inspection results and the possibility of splitting the lot into two or more parts. The last two of these procedures apply for only that fraction of the lots in which a significant number of defective parts are found.

People in four different divisions of the organization (seven different departments) are directly involved in the routine of this system. For any one lot, the number of different people required to take action or make decisions is not less than eight (if all parts are accepted) and may exceed 20 (if both nonconforming and unacceptable parts are found). Obviously, there are problems of coordination even in administrative functions as simple as this.

1.5 REQUIREMENTS FOR A SYSTEM

In order to judge how satisfactorily an existing or proposed system is, a set of requirements is useful as a starting basis of inquiry. The following is not a complete list of criteria; it is merely a selected group of ideas covering the major factors which influence the success of a system. Furthermore, the ideas presented below are neither mutually exclusive nor independent of each other. But they are useful in diagnosing the deficiencies of a system.

1.5.1 Seven specific requirements. 1. A system must fulfill its purposes ef-

fectively. To determine how well it does this, its purposes must be clearly defined and stated in terms of actual benefits expected. It is then possible to compare results with plans by asking and answering specific questions. Does the system adequately control that certain activity? Does it actually reduce this cost? Is this information sufficiently accurate and current? How frequently does that extra expense result from a failure in the system? Unfortunately, such questions are seldom asked until a deficiency becomes obvious as a result of trouble.

2. Another requirement is speed. Delay in administrative processes can be very expensive, and in some cases may even threaten the success of the business. Excessive time lag can nullify the value of a control report or notice of change, or may result in loss of a customer or an opportunity. Also, slow, cumbersome systems tend to discourage people, sap initiative, and lower morale. What is needed is fast handling on the average and reasonable speed in the worst cases.

3. A system should minimize the confusion, and the consequent loss of time and effort, that results when repetitive administrative activities are not adequately planned. It must provide acceptable answers to such questions as: "What do I do with this?" "What information do they need?" "Who has to approve these?" "How do we handle one like that?" A complete set of standing plans is needed. Within the functional scope of the system, all possible questions of procedure and policy should be covered in one of two ways: by setting up the answer in advance, or by referring it to a proper level of authority when the problem comes up.

4. Another factor of importance is the cost of the system. An appropriate criterion is that it should cost less in the long run than any other way of accomplishing the same results. This implies that someone must devise and propose one or more alternative systems to compare it against. An existing system should be subjected to such a challenge periodically. Also, of course, any proposed system should be given this same examination before it is approved and installed.

5. A system should be adaptable. Its mechanics should be built on a sound foundation of basic plans and should be designed and assembled in such a way that the system can be easily adjusted to changing conditions. Otherwise, it may require frequent overhaul, or become excessively expensive to operate or cease to fulfill its purposes satisfactorily.

6. A system must be acceptable to the management and the personnel engaged in its operation. All concerned must understand it, and therefore it must be simple and logical. In addition, the personnel must want to make it work, or it will ultimately be discarded. This is partly a matter of introduction. But it is also necessary that responsibilities are properly assigned, that work loads are reasonable, and that the system shall function smoothly.

7. The plans of the system must conform with the company structures of policy and organization and with external requirements imposed by custom and law. They must not violate superior decisions and regulations or conflict with the aims and requirements of other systems.

Summarizing the above, a system must:

1. Fulfill its purposes effectively.
2. Require minimum time to process each successive case.
3. Provide a complete set of plans.
4. Cost less than possible alternatives.
5. Be adaptable to changing conditions.
6. Be acceptable in the long run.
7. Conform to imposed restrictions.

1.5.2 Two general requirements. The first three of the above requirements have to do primarily with the benefits expected of the system. If it is effective, fast, and complete, chances are that it is producing the expected results. Assume also, that its cost is reasonable in comparison with other conceivable schemes for accomplishing these results. It is then proper to ask whether or not the value of the benefits produced is greater than the cost of the system.

A necessary objective in any enterprise is a net excess of receipts over disbursements sufficient to justify the investment of the owners and perpetuate the business. Any administrative activity within the company is worth while only if it contributes toward that objective. Consequently, a system should be expected at least to pay its own way.

Evaluating a system in this respect requires the point of view of an economy study in which the question is "Why do this at all?"* This approach is to ask what would be the actual differences in future money receipts and disbursements of the company in the long run if this system were dropped as compared to continuing to operate it. In other words, the "benefits" of a system should be measured in terms of the expected increases in future expenses that would result if the present system were eliminated.† And the "costs" of the system should be measured in terms of the actual decreases in future expenses that might be expected in this event. Of course, if a system provides a service which is essential for the operation of the company (e.g., a payroll system), it is quite clear that the benefits will exceed the costs. But it does not follow that such a system cannot be improved.

Ideally, all the costs and benefits of a system or procedure should be converted to dollars so that they can be combined in an appropriate way for easy comparison. As a practical matter, it may not be worth while or feasible to do this in any formal or detailed way. Nevertheless, it is always helpful to apply the above reasoning and point of view.

If it appears that the system cannot pay its own way, one of two actions should be taken—replace it, either in whole or in part, or eliminate it entirely. Replacement implies that a substitute scheme can be devised which will produce benefits at least equivalent to costs. This possibility brings out a further and even a more basic requirement for any system—*it should produce a greater excess of benefits over costs than any other available alternative*. Eliminating the system entirely may be viewed as one such alternative, and therefore the requirement that a system must pay its own way is really subsidiary to this one. So also is the requirement that it should cost less than any other way of accomplishing the same results.

* See Section 3. Also Eugene L. Grant, *Principles of Engineering Economy*, 3rd Ed. (New York: The Ronald Press Company, 1950), Chapters 1 and 2.

† Some administrative systems act to increase receipts of the company by increasing sales, improving credit collections, securing reimbursement for purchase returns, and so forth. Such increases in incomes have the same effect, in general, as reductions in expenditures; both are positive in the sense of being beneficial to the company. For the sake of simplicity, when system benefits are referred to in terms of decreased disbursements or savings, the possibility of benefits of the other type is assumed to be understood.

2. SOLVING ADMINISTRATIVE PROBLEMS

In most companies, there is a constant propagation of administrative problems. They arise in many ways. For example, a deadline is missed, a procurement mistake occurs, inaccuracy of time reporting becomes intolerable. Or someone finds out that an item of information is not what he thought it was. Or a piece of equipment cannot be located, or a large inventory discrepancy is discovered. When something like that occurs, corrective action may be initiated to save money for the company or to provide protection against personal criticism in the future.

Other problems appear in the form of new administrative requirements—another government regulation, a clarification of personnel policy, a switch in organization or readjustment of departmental responsibilities. Events like these often make it necessary to add to or modify existing systems. Although such changes ordinarily can be anticipated, they are often left to the last minute and sometimes create minor procedural crises.

2.1 A POOR APPROACH TO SYSTEM AND PROCEDURE PROBLEMS

A common way of meeting these administrative problems is to adopt some obvious countermeasure requiring a minimum of time and trouble to conceive and put into effect. Such a solution is seldom the best, and has a good chance of turning out to be unsatisfactory. Nevertheless, in the face of immediate difficulty, the tendency is to avoid adequate investigation and consultation, and jump directly to action along the line of least resistance. The following are some of the typical results of this approach.

2.1.1 Start an independent procedure. This practice is well illustrated by the following example. A foreman for a small machine shop was criticized for not starting the assembly of a certain unit in time to meet the delivery schedule. Subsequently, he requested a complete set of drawings. Heretofore he had received only drawings for parts to be made in the shop, and was never sure when he had all the necessary purchased parts on hand. In effect, what he intended to do was analyze the drawings and make a complete bill of materials list for himself. Then as purchased items were received, and shop-made parts completed, he would check them off on his list. As soon as the list was completely checked out, he would commence assembly.

Unfortunately, there were several things wrong with this scheme. In the first place, there was no provision for maintaining his set of prints up to date with the latest revisions. Secondly, many of the parts were common to different product units. Also, the foreman was planning to add a burdensome clerical task to an already hectic day, and to spend a considerable amount of money for additional blue prints and filing equipment. What the foreman did not know was that up-to-date parts lists were available for reference or reproduction in engineering. And he did not consider the possibility that the information he needed could be derived readily from the purchasing records. Obviously, there were better ways to solve his problem.

2.1.2 Extrapolate an existing procedure. Another way to answer an administrative problem with little effort is to make use of existing procedures and forms. For instance, in a certain company several problems came up in connection with closing out equipment fabrication jobs and transferring the completed equipment from maintenance to production. A fiction of paperwork was subsequently invented to make the procedures for constructed items completed the same as for purchased items received. This involved, primarily, writing and distributing a receiving report. Later on, this idea was extended to include writing a purchase order for each equipment construction job. The resulting ramifications in purchasing, sales, maintenance, shipping and receiving, and accounting were indeed remarkable. At one point, it appeared that in order to terminate the paperwork chain, it would be necessary for accounts receivable to bill accounts payable. Then, a voucher check would have to be prepared, signed, endorsed, and deposited in the bank. This would clear up the matter by transferring the tail of the confusion to the bookkeeping system of the bank.

In general, extrapolating a procedure or using a form for abnormal purposes, may create more problems than it solves. One source of trouble is that the special application of the procedure often requires special treatment of details all along the line, even though the general pattern may be standard. This leads to confusion and supervisory problems. Another is that unless all the normal procedures apply to the new case, it may be difficult to utilize certain ones without involving the others. One likely consequence is undue expense.

2.1.3 Author a new form or report. This possibility is apparently very attractive to clerical workers and supervisors of administrative activities. The line of reasoning often goes like this: "This thing would not have happened if we had known about so-and-so. There-

fore they will have to send us a report each time. For this we will need a form." Thereupon a form is penciled out and given to a stenographer to polish up and duplicate. Such questions as who will make it out, how many copies are required, and how they will be used, may get little attention or may be deferred until the form is ready for use. It is often unclear what items of information are required, and why, and from what sources they will be obtained.

An example of this occurred in one company when a customer requested a monthly report of the number of units containing their parts and materials which were scrapped, broken down by reasons for rejection. Someone in the sales department invented a new form entitled "Scrap Report." (There were already three forms with this name.) The new form was filled out by a clerk in the production department, who devised an ingenious method of finding out about scrap, recording it, and summarizing it each month for transfer to the report. This required perhaps an hour a day plus six hours at the end of the month. The resulting information reported to the customer (re-typed in a different form) was misleading and inaccurate, and in no way reconcilable with existing records of quality results.

Starting a new form without proper planning is merely a way of backing into extemporary procedures. Both the form and the procedures are likely to be expensive to use and still may not accomplish the desired result.

2.1.4 Increase the number of copies of an existing form. This is often done to solve a temporary problem or provide someone information which they think they need for reference or protection. One example of this came to light in a pathetic letter from one plant of a large company engaged in a defense contract. Following a full explanation of a need for three copies of receiving reports originated at that plant, were the following comments: "Four months ago we requested that the receiving report be increased from six copies to eight copies, so that we could send five to the main office and keep three ourselves. Last week we received a supply of the new eight-part receiving report. But today we got a letter from Mr. Blank instructing us to send seven copies to the main office commencing immediately. This puts us right back where we were four months ago with only one copy for ourselves." It turned out that one copy requested for the originating plant was to be used for a purpose that would duplicate work done at the main office. Also, by proper routing and distribution, and by eliminating unnecessary uses and files, the main office could get along with only four copies. A total of six were needed, not eight or ten.

The cost of an extra copy itself is not very important ordinarily. But an additional copy means additional procedure. The handling, use, filing, and ultimate disposition should be planned and justified before the extra copy is requested.

2.1.5 Make a blanket rule. If the trouble at hand is not the result of a direct violation of an existing policy or procedure, a first impulse may be to make a new rule. In some cases this is effective, worth while, and necessary. However, many rules which are handed down at a time of administrative trouble turn out to be unenforceable, unrealistic, or unduly restrictive. For example, unknown to the purchasing agent, an engineer investigated the capabilities and costs of parts made by a new process. Because of a misunderstanding, he accepted delivery of a small "sample order" for which a fifty-dollar invoice was later received. Subsequently, a memorandum was sent to all department heads stating that hereafter "no contacts shall be made with vendors except through the Purchasing Department." It soon became necessary, of course, to make numerous exceptions and amendments to this rule in order not to discourage the flow of technical information into the company, and to facilitate various classes of purchases. The instigation of such a broad and restrictive rule as this is clearly not warranted by an occasional fifty-dollar mistake.

Some rules that come about in this

way can be very wasteful. If enforced literally, the rule cited above would require an unnecessary amount of time and effort of people needing information and performing liaison functions with vendors, as well as for people in the purchasing department. Or a rule can result in a considerable waste of materials. Suppose, for example, in an effort to reduce breakage, a rule is made that broken tools will be replaced with new ones only on the authority of a stores requisition signed by a foreman. This would undoubtedly reduce the number of broken tools turned in at the tool crib, but it is unlikely to affect the number of new tools issued.

Closely allied to the new rule idea is the "get tough" line of attack. Policies and procedures need to be enforced. But lack of conformance is often a result of weakness in the procedure, rather than indifference or carelessness of employees, or lack of supervision. Many apparent violations are the result of well-intended efforts to follow incomplete or unclear procedures. In other cases, what is considered to be an acceptable level of conformance may not be realistic. This is often the case where the performance of a procedure depends too heavily on someone's memory, or where a clerical function is delegated to somebody lacking the necessary skills and interest.

In making new rules, and restating old ones, adequate thought should be given to all the consequences and to whether or not its requirements are realistic. Poor rules can be expensive, not only in dollars and cents, but also in their effect on the attitudes of the employees toward their jobs and their company.

2.1.6 Acquire a new machine or device. Sometimes a problem of accuracy, speed, or control results in a hunch decision to buy a machine or piece of equipment, or even a whole "system" of mechanical devices, without a clear picture of how it will produce the desired results or what it will cost to operate. Machines and devices are only tools for a system. They must have information brought to them, put into them, and taken from them. They impose special requirements and extra costs that tend to offset labor savings and other benefits. While modern office equipment can be extremely worth while, each item should be required to pay for itself and provide a satisfactory rate of return on the investment. In general, it is not a good idea to buy a systems tool and then figure out what it will do and how to use it. What may appear to be a cure-all for existing problems may turn out to be an expensive experiment if such a decision is made without critical examination.

2.1.7 Hire more people. Continuing administrative problems are often met by adding people to the work force. For instance, if jobs are frequently falling behind schedule in the shop, one answer is to add follow-up men or stock-chasers. Or, if time and production reports are not acceptably accurate, to add time checkers. Each such person represents continuing future expense. It may be easy to justify each of these extra people, in turn, as compared to doing nothing about the problem. But often there are other alternatives which should be considered. Chronic troubles, such as failures to meet schedules, tie-ups in coordination, or inaccuracies in records, indicate basic deficiencies in the administrative mechanisms. Many of these persistent difficulties could be eliminated at the source or systematically controlled at considerably less expense.

2.1.8 Borrow a system from some other company. Outright adoption of a system because it was successful somewhere else rarely turns out to be satisfactory. In the first place, the situations, the people, and the problems of two companies, even in the same industry, are seldom more than superficially alike. But perhaps even more important is the fact that a system requires more than forms, equipment, and procedures to operate successfully. It needs roots of policy, a suitable organizational environment, and a large mass of experience and detailed knowledge which cannot be transplanted. Also, it must dovetail into other systems on which it depends and which depend on it. What often

happens when this is attempted is a prolonged struggle to fit the situation to the requirements of the borrowed system, and vice versa, until one of two things results. Either the system is thrown out, or it is made to work at considerable expense. Even so, it is not likely to produce maximum benefits.

2.2 ADMINISTRATIVE PROBLEMS ARE SELDOM LOCALIZED

Frequently it pays to look behind the immediate difficulty. Many problems which sprout up in one department are merely evidence of larger problems whose roots are elsewhere. Treatment to cure the symptom may only disguise the disease, and it will continue undiagnosed to pop up at other points and require additional treatment.

For example, the cost accounting department of a manufacturing plant was having difficulty processing multiple-item stores requisitions because some of them were coming through from production control with one or more of the items unpriced. Because it was undesirable to delay the posting of the priced items, accounting proposed that a separate requisition slip be made out for each item issued. But this would eliminate the possibility of using pre-printed copies of assembly orders as stores requisitions, and would require a considerable amount of extra writing for all multiple-item issues. A compromise was reached whereby production control would mark off any item appearing on a multiple requisition for which no price was available and make out a separate slip for it. Thus the amended multiple requisition could be processed in accounting and the slip for the deleted item could be held until the price was available. Although this solved the immediate problem, it did nothing to eliminate the reasons why prices were not available for many purchased and manufactured parts until some time after they were issued from stock. Investigating this question pointed the way to correcting this and several other deficiencies of greater importance.

The point of view of an individual responsible for one activity or department has certain inherent limitations with respect to systems problems. Necessarily, his primary concern when trouble occurs is how it affects the functioning of his group. He is not expected to try to solve other people's problems, and may meet with considerable resistance or criticism if he does. Also, a person in one department is often not sufficiently aware of the activities and objectives of other groups to properly appreciate all the interdepartmental aspects. Consequently, many little problems, and some important ones, are disposed of in a manner which is not always best for the over-all interests of the company. This was illustrated in several of the cases cited in Art. 2.1.

Another limitation of the departmental viewpoint is the tendency to view with some distrust the records and reports of other groups, and to set up independent checking, recording, and filing activities for self-protection. For example, in the process of transferring material by messenger from Dept. A to Dept. B, it was being counted three times. Each party retained a signed and countersigned copy of the transfer slip, and accounting received a fourth copy carrying all three signatures. Three of the four copies were filed in essentially the same way in different departments. This is a simple case. Sometimes defensive record-keeping involves such absurdities as complete little timekeeping systems, sets of private logs and registers, and schemes for following up on the results of someone else's follow-up system. Not uncommonly, such things are started as a result of a single instance of error or failure in another department. A further consequence of departmentalization is the reluctance of a supervisor to add work in his department in order to save work in some other department. This is particularly noticeable where there is an effective system for controlling overhead expenses by departments.

Clearly, all decisions between alternatives of system and procedure should be made on the basis of what is best for the company as a whole.

2.3 IN SOLVING ADMINISTRATIVE PROBLEMS, AVOID UNNECESSARY HASTE

There is always a certain amount of urgency connected with systems problems. Sometimes a reasonable answer right away is more desirable than a better answer at some future time, particularly if there is a strong chance that continuing in the present way might have serious consequences. But even in the most pressing cases, a few hours or perhaps a few days of investigation and diagnosis can be very well spent. Usually, the problem has existed for some time without being recognized. Sudden discovery should not dictate sudden action.

It is frequently enlightening to pursue the question of just what happened to bring this problem to the focus of attention right now. This is partly a matter of examining the evidence that a problem of consequence exists at all. It may have been a very rare event for which the existing defenses are reasonably adequate from a long-run point of view. Or the real cause of the trouble may be found to be quite different from what was originally assumed. Or the state of concern present at a managerial level may be traceable through a series of misunderstandings, amplifications, and poor assumptions, to the well-intended complaint of a person not in a position to see the whole picture. Poorly conceived plans of corrective action may sometimes be headed off by a little investigation of this sort.

As a practical matter, many of the "sudden" problems for which precipitous action is proposed, are seldom as urgent as they may seem. They usually have a way of becoming less important and considerably less pressing if action is deferred. Sometimes they disappear in the course of solving a more basic problem. Or difficulties in several departments may turn out to be interrelated and can be exterminated as a group.

Also, if final judgment on an administrative matter is postponed, it may be seen in a better light when taken up again. A case of this kind came up during the preliminary stages of installing a departmental cost control system. Several department heads asked that a form be devised to request one department to do work for another and to authorize charging of the necessary time and materials to the overhead account of the requesting department. The arguments for this were (1) if a department head is to be responsible for costs, he should have control over everything charged to his account, and (2) the department providing the service should have a written work order to avoid misunderstandings and to prove that the expenditures were authorized. The form was designed and the procedure was planned and routed for comment. Because of other pressing matters no further action was taken for several weeks. Then, upon reviewing the matter, the chief accountant became aware that there would be little or no benefit to the company as a whole in return for the writing, signing, handling, using, and filing of this proposed form. The monthly tabulating-machine summary of departmental costs gave detailed listings of all such interdepartmental charges. Hence, each department head was afforded adequate opportunity for after-the-fact control in lieu of prior approval. Where necessary, written work instructions could be transmitted by memorandum. And the protective value of an authorizing signature seemed to have little real merit. The procedure was tabled indefinitely.

2.4 AN ANALYTICAL APPROACH

As was pointed out in Arts. 2.1, 2.2, and 2.3, busy people tend to jump to conclusions about the solution to problems of system and procedure. One common practice is to seek an

answer directly in terms of forms, equipment, people, or policies, without benefit of conclusive analysis. This almost inevitably results in failure to recognize one or more superior alternatives. And it precludes the careful planning necessary to avoid serious defects in the plan adopted.

A better approach would be to follow the simple plan of attack outlined below.

1. *Investigate and diagnose* the nature of the trouble and its causes (or the new requirements that must be met). Trace back to original sources.

2. *Describe the problem* in terms of the real benefits sought.

3. *Turn up alternative solutions*—as many as practicable, including the possibility of no change at all.

4. *Plan each alternative* at least to the extent necessary to evaluate its probable consequences (costs) and its expected results (benefits).

5. *Compare the various alternatives* from the viewpoint of the company as a whole, and select the one which would appear to offer the greatest net difference between benefits and costs.

For very simple problems of policy, procedure, or forms design, this whole line of reasoning can be compressed into a few minutes of conversation and doodling. For complex system problems in which considerable sums of money are involved, several man-weeks or months may be necessary and worth while. But regardless of the size of the problem or how urgently a solution is needed, this type of analysis is necessary to make reasonably sure that some excellent possibility is not overlooked, and that the proposed plan of action is feasible and will clearly pay.

3. SYSTEM IMPROVEMENT STUDIES

The administrative systems of industrial organizations are a fertile field for improvement. Waste is typical. In most systems it is to be found in two forms—excessive expenditures, and failure of the system to achieve a reasonable fraction of the benefits potentially available within its area of influence. The first is a matter of unnecessary procedure and poor methods. The second is a matter of ineffectiveness and inadequacy. Both are important sources of savings. Reducing this waste should be the central objective of a continuous and coordinated program of system studies.

3.1 FIVE WAYS TO IMPROVE A SYSTEM

In any given area of system and procedure, improvement is achieved only by making changes, additions, and deletions in such a way as to increase the net difference between the benefits produced and the costs incurred. There are five fundamental ways in which this can be done (see Fig. 6.3):

1. By decreasing the operating costs of the system.

2. By increasing the real benefits.

3. By concurrently decreasing operating costs and increasing benefits.

4. By eliminating or reducing certain benefits if a greater savings in administrative costs can thus be gained.

5. By adding or increasing certain administrative costs in order to gain a greater increase in benefits.

Of these five possibilities, the first three are obvious. The last two are not so obvious. They are often overlooked, particularly as they might apply to systems that have been operating for some time without benefit of serious review. In seeking to improve a system, it is important to keep all these possibilities in mind and to avoid undue emphasis on one, such as (1) or (2), to the exclusion of the others.

3.2 OPPORTUNITIES FOR IMPROVEMENT

Article 2 dealt with the correction of functional deficiencies of various kinds, but was limited to those which turn up more or less by themselves—in the form of trouble or new requirements. Typically, such problems are looked upon as something to be dis-

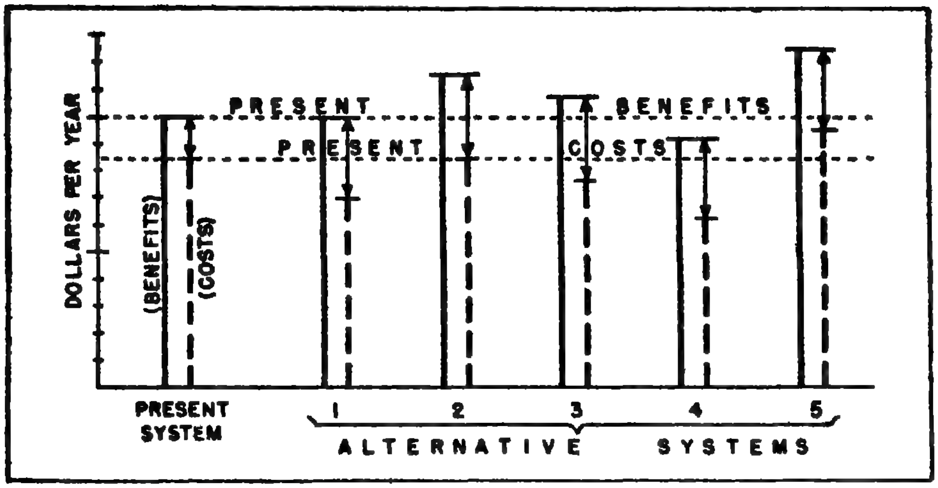


FIG. 6.3 FIVE POSSIBLE WAYS TO IMPROVE A SYSTEM.

posed of rather than opportunities for improvement. An administrative difficulty should be considered as merely evidence of the need for a study of the system. Rather than seeking to cure the immediate trouble at any cost, such a study should be undertaken to discover and put into effect as many worth-while changes as possible.

Efforts toward functional improvement should not, of course, be restricted to areas in which an obvious problem exists. Only a small part of the functional deficiencies of a system ever become apparent as the result of trouble. And usually these are not as important to the company as the many possibilities for new benefits, and opportunities for increasing present benefits, which lie dormant. Ordinarily, if a system has been operating without trouble or complaint it gets very little attention; it is assumed to be fulfilling its purposes fully and effectively. But this is seldom more than partially true. Analysis of existing systems inevitably turns up many ways to improve and extend their effectiveness, and thus increase their net benefits.

With respect to costs, there is room for improvement in any system, and frequently the possibilities are remarkable. Unlike functional deficiencies, excessive and unnecessary costs of administrative activities seldom cause sudden trouble or criticism. In fact, inefficient methods and unnecessary work have a way of becoming less conspicuous the longer they persist. They defy expense control schemes by diluting the averages against which current costs are compared. And they tend to weather economy drives and across-the-board cutbacks of administrative expenses. The only effective way to locate and focus attention on these opportunities for cost improvement is to analyze each system periodically and to compare the existing methods and procedures against possible alternatives.

3.3 A PATTERN FOR SYSTEM STUDIES

The following outline represents the analytical process which is found by professional system analysts to be most efficient and most likely to produce satisfactory results. It is intended as a guide for action and a checklist of things to consider.

If it is reasonably comprehensive, any such outline appears formidable. Fortunately, there are few system studies in which it is necessary to carry out all the steps in detail. A system analyst or supervisor always has a lot of pertinent information and ideas to begin with. Also, in most cases there are a number of points which are either obvious or not important. The simpler the system the more this is true.

3.3.1 An outline for a major system study

1. *Planning*
   - A. Make a preliminary survey.
   - B. Define the scope of the study.
   - C. Evaluate the cost of the study.
2. *Analysis*
   - A. Organization and personnel.
   - B. Responsibility distribution.
   - C. Policies, terminologies, and deficiencies.
   - D. Procedures and methods.
   - E. Information flow.
   - F. Workload—classes, quantities, and variability.
   - G. Equipment and layout.
3. *Design*
   - A. Develop basic plans.
   - B. Plan the assignment of responsibilities.
   - C. Correct deficiencies in policy.
   - D. Plan the procedures and flow of information.
   - E. Define and justify each item of information.
   - F. Select the system techniques and devices.
   - G. Design the forms and reports.
   - H. Plan the work methods.
   - I. Improve the new system.
4. *Implementation*
   - A. Prepare diagrams and/or written procedures.
   - B. Obtain suggestions and approvals.
   - C. Plan the installation.
   - D. Install the new system; follow-up.

In general, it pays to give some attention to each point in the above outline, and to proceed roughly in the sequence indicated. A methodical approach like this saves time in the long run and has a much greater chance of yielding improvements which are both significant and durable.

The arrangement of this suggested pattern for system studies in outline form carries several implications which are misleading. A first impression is that each successive point should be taken care of before proceeding to the next. This is neither practicable nor desirable. Effort on the four main phases properly should overlap. Likewise, within each phase it is usually helpful and more efficient to pursue several of the tasks at the same time.

Another false inference is that the individual undertaking or coordinating the study should be able to devote his full time and attention to it until it is completed. Although this may get the job done sooner, and may be somewhat more efficient, it is certainly not essential for the success of the study. Consequently, this plan is no less suitable for administrative supervisors than for staff analysts or consultants.

3.3.2 A special case—devising a system for a situation where none of its functions has ever been performed before. Strictly speaking, such a project only arises in connection with a proposed new plant, program, or company for which suitable systems must be developed prior to the start of activities. However, a somewhat similar situation may occur in an expanding company where the development of systems has seriously lagged the progressive division of labor and departmentation. In other words, there may be very little system to study and improve. In a case like this, the general plan of a system study is essentially the same as outlined in Art. 3.3.1, with appropriate modifications, of course. In the analysis phase, for example, the emphasis is shifted from details to general plans, and from obtaining data to estimating them.

As a rule, designing a system "in a vacuum" is considerably more difficult than improving an established one. There are no activities to study, no past records to obtain information from, and no present forms to trace and analyze. Policies and assignments of responsibility may be fuzzy. Many of the things ordinarily derived by analysis of the existing system must be supplied from personal experience, imagination, and information from outside sources. And, of course, there is no opportunity to try out ideas in advance. On the other hand, there is greater freedom of choice, lack of resistance to change, and the problem of gaining acceptance and approval is likely to be somewhat simpler.

3.4 PRELIMINARY SURVEY

A preliminary survey should be made for any system study in virgin territory, and for any major review not associated with a recent project. The purposes of such reconnaissance are several:

1. To establish a clear idea of what is to be achieved, what it will cost, and how long it will take.
2. To obtain sufficient information with which to plan the study.
3. To obtain useful background information.
4. To secure the cooperation and endorsement of all responsible managers, department heads, and supervisors.

The best way to accomplish this first phase of the study is to interview briefly the managers and department heads directly concerned. For simple studies this is usually combined with the analysis phase.

3.4.1 Determine the objectives of the study. Although the general purpose of any system study is improvement, there are usually some explicit objectives such as solving certain problems or simplifying certain tasks.* Frequently, interest will be focused on a particular area of system by one person for one reason, and subsequent investigation will bring out a number of additional problems or possibilities for cost reduction. These suggestions should be collected, clarified, evaluated, and condensed into a specific set of things to be accomplished. This should be agreed upon as the minimum goal of the study.

3.4.2 Determine the framework of organization. A working knowledge of the organization, and the relationships between individuals and groups, should be acquired before starting detailed investigation. What is needed is both the structure of supervisory authority (who reports to whom), and also the structure of technical authority (the functional assignments of the various groups). If an up-to-date organization chart is not readily available, it is best to sketch one showing names, job titles, and functions. It should at least include all groups which might be affected by the study, and their respective supervisors, and should be carried back to the individual whose span of control covers all these groups.

3.4.3 Seek background information. It is always helpful to find out as much as possible about what has gone before, and what the present trends and future expectancies are, with respect to the administrative activities to be studied. Some knowledge of how the present system developed is likely to be very useful. And, of course, any reliable opinions about future changes in work load, organization, policies, or related systems, may have a direct bearing on improvement decisions. In addition, to supplement the official organization data, information about the actual working relationships between groups, and some slant on the interests and attitudes of key individuals, are likely to be of value.

3.4.4 Secure proper sanctions and enlist cooperation. Obtaining cooperation, enthusiasm, and authoritative approval for a study is sometimes a problem in itself. It is to be expected that a system analyst or administrative supervisor will encounter defensive reactions, indifference, and limited points of view in the course of any major study. Discussion of the causes and consequences of these phenomena, and how they can be avoided and deflected, is beyond the scope of this section.* However, as a matter of procedure, it is best to:

1. Obtain prior approval and support

* See Section 5, Art. 3.9.2.2 for a list of some of the common types of special objectives of system studies. Also, Neuschel, *Streamlining Business Procedures*, pp. 105-12.

* See Neuschel, *Streamlining Business Procedures*, pp. 118-21. Also John H. Ross, *Technique of Systems and Procedures* (Office Research Institute, Inc., 1948), Chapters II and III.

at an appropriate level of management.

2. Let everyone concerned know what is being planned, and why, and how they can participate.

3. Make any special requests and effect all changes through normal lines of technical and supervisory authority.

3.5 THE SCOPE OF THE STUDY SHOULD BE DECIDED IN ADVANCE

A system study has a way of spreading out in all directions from the area originally contemplated. In the process of probing back to the sources of information used, and tracing out the destinations and purposes of information produced, new problems and opportunities for improvement are discovered. It is frequently tempting to expand the scope of the study, little by little, until it becomes unmanageable and the original objectives get lost in the confusion. To avoid this, it is a good idea to define appropriate and reasonable limits for the study.

Investigation and corrective action in other areas should be limited to those necessary for the immediate purposes. In many cases, methods and procedures lying outside the study limits need to be changed in order to accomplish improvements within the defined area. Side problems like this must be solved in the course of the present study. But usually there are many other deficiencies in these related procedures which can be tolerated a little longer without serious effect. Unless their subsequent correction is likely to make the results of the present study obsolete in the near future, it is best to defer action rather than divert time and attention from the original job.

3.5.1 Establishing the study limits. Fixing the scope of a system study is essentially a matter of defining the scope of the system to be studied, which in turn is a matter of isolating a particular area of administrative activity for analysis. But to define the scope of a system in a satisfactory way is not always simple. One difficulty arises from the fact that a system has many dimensions. Another difficulty is that the systems within an industrial organization are so interconnected and interdependent that any boundaries drawn between them are necessarily arbitrary.

To completely define a system, limits must be established for all its parameters. But it is important to begin with those which are fundamental. A common mistake is to mark out the boundaries of a system in terms of physical factors, such as forms, locations, people, and equipment. These are superficial characteristics of the system. To establish the scope of the system in such terms severely restricts the thinking that goes into the analysis and subsequent attempts at improvement. The limits so established are usually incomplete, and sometimes very poorly chosen. The consequences are likely to be duplication and waste of improvement effort, and procedures which overlap, conflict, and are poorly integrated.

A better plan, for important system studies, is as follows:

1. Clearly define the administrative *functions* to be studied and the *range of application*.

2. Decide where to break off each sequence of procedures crossing the fringes of this functional area.

3. Identify the items of information (and the forms on which they are carried), the people (and their departments), and the equipment employed in the procedures to be studied.

3.5.2 Define the functions and range of application first. Basically, *the scope of a system is determined by its administrative purposes*. Therefore, the two fundamental parameters of the system which should be defined first are its *functions* and its *range of application*.

For most systems, the *range of application* is specified in terms of the classes of items for which it applies. For instance, the system described in Example I (Art. 1.4) applied to lathe tools (which accounted for nearly all of the cutting tools that were being sharpened by machine operators). The study might have been expanded to include milling

cutters, drills, and other resharpenable tools; or it might have included all tools loaned from the tool crib. For the system analyzed in Example II (Art. 1.4), the range of application covered all purchased parts and subassemblies. Excluded were purchased items requiring less formal or routine inspection, such as raw materials and tools. In these systems, as in many others, the object of the system's function is a physical item of a certain class. In other cases, the basic item which the system applies to or acts upon may be a more abstract thing, such as an order, a request, a task, a shipment, or a report.

The *functions* of the system should be stated in terms of administrative activities or tasks pertaining to the specified classes of items. In Example I, the general functions were *supply* and *control*. More specifically, the functions of this system could be defined as supplying sharp lathe tools to the shop, keeping track of their location, and controlling them with respect to specifications, quantity, and cost. In Example II, the general function was inspection of incoming parts. A more detailed description would be: (1) inspecting purchased parts in accordance with predetermined plans, (2) handling and disposing of accepted and rejected parts, (3) transmitting information necessary for subsequent administrative processes, (4) notifying the vendor of non-conforming parts accepted, and (5) returning and back-charging unusable parts.

3.5.3 Each system study should be part of an integrated program. From a short-run viewpoint, any definition of the scope of a system to be studied is acceptable if it is suitable for the immediate purposes. Nevertheless, it is always helpful to consider first the entire field of related administrative activities in which the intended study area lies. This usually leads to a somewhat different and more definite idea of the scope and purposes of the immediate study. And it pays off in long-run benefits, some of which are as follows:

1. Avoiding inconsistencies, conflicts, and duplications between different procedures bearing on the same administrative activities.

2. Avoiding duplication and obsolescence of system improvement efforts.

3. Avoiding confusion caused by lack of basic definitions and the use of non-standard terminologies.

Suppose, for example, a study of the procedures for controlling, reporting, and recording changes in location and departmental assignment of capital equipment is proposed in a medium-sized company. The objectives are to improve the relative accuracy of the property accounting records, for cost distribution and fire insurance reasons, and to attain adequate location control, primarily of the more portable items. Also, there is the possibility of cost savings by reducing the frequency with which physical inventories must be taken and reducing the time required to find specific items for various reasons. Immediately many questions arise. What is meant by "capital equipment" for the purposes at hand? Should relatively expensive durable tools be included? What about new equipment coming into the system and old equipment going out? When is an item "transferred," and when is it just "borrowed" or removed to a more convenient spot for repair or maintenance? Decisions on all such questions must take into consideration all of the related procedures—those which have been improved and standardized as a result of previous studies, and those which have not yet been studied adequately. Before attempting to plan the present study, it would be worth while to take a reconnaissance of all the related procedures and records concerned with the durable properties of the company, particularly if this has not been done before.

Figure 6.4 is a simplified representation of the procedures which might somehow be directly involved in this proposed study, classified by administrative function and type of property. The heavy lines are meant to indicate boundaries between systems as they might be marked out for the purposes of analysis, improvement, and subsequent proce-

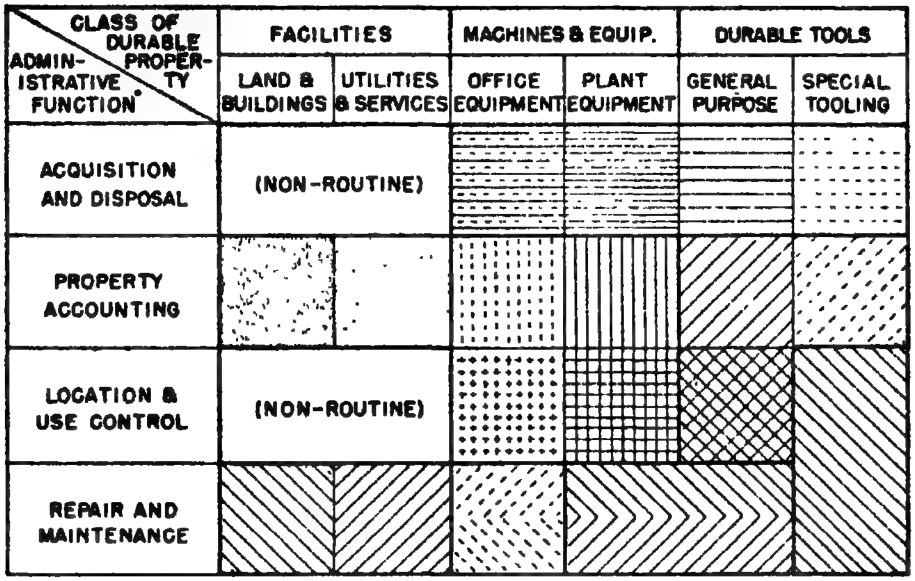


FIG. **6.4** DIVISION OF A FIELD OF ADMINISTRATIVE ACTIVITY INTO SYSTEM AREAS.

dures control. The area contemplated for immediate analysis is presumably some combination of the blocks in the center of the table. Just what should be included needs to be clarified before the study is undertaken.

Clearly, boundaries are between adjacent systems. Establishing limits for one system necessarily establishes partial limits for related systems. If system studies and their products are not to overlap and conflict, decisions on the scope of such studies should be coordinated.

Obviously, there are many other reasonable combinations of the 24 blocks shown in Fig. 6.4. Also, there are many other ways such a table could be divided with respect to functions or with respect to classes of items. For instance, in this case the range of application could have been broken down in any one of the following ways:

1. By ownership—company, government, customer, lessor.
2. By method of acquisition—purchased, constructed, rented or borrowed.
3. By first cost valuation—i.e., up to $100, $100 to $5000, over $5000.
4. By physical characteristics—such as floor space, portability, or severability.
5. By organizational assignment—i.e., production, maintenance, experimental shop and laboratory, etc.
6. Expected service life—i.e., less than two years, two years or more, duration of job, leasehold period.

The last four of these factors were taken into account to some extent in the breakdown shown in Fig. 6.4, and the definitions of the six classes of items shown would no doubt establish lower limits on such factors as first-cost valuation and expected service life. Other differences between the various items covered by any one of the systems would require variations in procedure.

What is desired in breaking down a large area of administrative activities such as this, is that each system shall be:

1. Reasonably homogeneous throughout its range of application.
2. Relatively independent of adjacent systems.
3. Small enough, in number and complexity of procedures, to be a convenient and comprehensible study unit.

Usually no one plan is clearly the best. But any reasonable plan is better than none at all.

3.5.4 Completing and testing the scope of the study. Having marked out the general area of the study in terms of administrative purposes, it should then be defined in more detail from the

viewpoint of procedure content. The structure of procedures included should be complete and contiguous within itself.

The study should cover all applications of any procedures falling within the system limits. For instance, the analysis behind the system in Example I covered all the items being loaned from the crib and all the tools being sharpened in the tool room. This was necessary in order to devise a system for lathe tool bits which could be integrated with, or expanded into, a larger system covering all types of tools. In general, the study should cover all the alternatives and variations of the procedures included within the chosen range of application. If the range is sharply restricted for practical reasons, as in Example I, the excluded classes of items should be investigated sufficiently to avoid undesirable specialization of any new procedures developed for the limited application.

Similarly, the administrative functions included in the study area should be tested with respect to procedures. There are always procedures at the fringes of the system, on which it depends or which depend on it, that are not wholly owned by the system. Unless recently reviewed in another study, each of these must be investigated if it might reasonably affect, or be affected by, changes within the study area. But for the purposes of improvement and procedures control these procedures may or may not be included in the system. This is illustrated in Example II. The receiving and receiving report procedure was omitted from the diagram because the inspection system applied to only a modest fraction of the various kinds of items received, and there was no intention of disturbing the receiving segment of the procurement and supply cycle in this study. However, at the other end of the system, transmitting and posting the quantity accepted to the inventory record was shown for the sake of clarity and reference even though it is clearly a part of the inventory control system. This is in contrast with the entire set of procedures for returning and securing credit for rejected parts which was shown because it was considered to be wholly and exclusively within the scope of the system.

Any decisions about the procedural content of the system prior to undertaking the study presuppose some knowledge of what is being done now and some prediction of the possible structures of procedures that may result. Obviously, pertinent information and ideas accumulate during the analysis, and flaws in the original plan will become apparent. Thus the preliminary definition of scope should be open to criticism and subject to change as the study progresses. Nevertheless, it is always worth while to have a guiding plan and to attempt to predict the results.

Defining the area of a study by its administrative purposes and procedures necessarily cuts across other dimensions of the system. Some of the people and equipment will be found to be engaged full time; others only infrequently or periodically. And they are usually scattered both physically and organizationally. Information, and the forms (or other means) for transmitting it, will flow in and out across the boundaries of the area marked out. (This is true no matter how the system is defined.) A preliminary attempt to list all the people, departments, machines, devices, and forms involved in the present system is frequently helpful in planning and conducting the analysis of the study.

Clearly, the purpose of defining the scope of the system to be analyzed is not to restrict investigation strictly within rigid limits. The idea is to concentrate effort toward achieving definite objectives with respect to a definite system. Investigation outside of this system should be viewed as a necessary supplement to the analysis of the system itself.

3.6 THE COST OF A STUDY MUST BE RECOVERABLE

Obviously, there is a point of diminishing returns for the amount of time that can justifiably be spent in

improving a system or procedure. From a long-run point of view, the time devoted to system study by the analyst, supervisors, and other people, should be valued at their respective hourly rates plus a reasonable allowance for variable overhead costs. This and other incidental costs of a study are justified only if there is a reasonable expectancy that they can be recovered, with a return, in additional savings accruing from the new system during its foreseeable life.

In an expanding company, for example, it would clearly be unwise for an analyst or a supervisor to spend two weeks to realize an annual saving of $75 in clerical labor and supplies. On the other hand, three to six man-months would be well spent in developing a better scheduling system which would increase administrative expenses by $2000 a year, but save seven man-and-machine hours a day and reduce inventories $40,000.

To evaluate the probable costs and the potential savings of a major system study may require some preliminary analysis and planning. For a simple study, a rough mental calculation will do. Nevertheless, a prior judgment should be made in each case.*

4. SYSTEM ANALYSIS†

The surest and quickest way to maximum improvement is by thorough investigation and systematic analysis of the information obtained therefrom. Professional analysts agree that the time spent making an exhaustive investigation not only improves the results, but also saves time in the long run. The alternative is to make unnecessary assumptions, either knowingly or unknowingly. These assumptions frequently lead to wasted effort and unfortunate decisions.

The major purposes of the analysis phase of a study are:

1. To collect all available facts, opinions, ideas, and miscellaneous information relating to the system with respect to:
   - A. organization and personnel
   - B. responsibility distribution
   - C. policies, terminologies, and definitions
   - D. procedures and methods
   - E. information flow
   - F. work load—classes, quantities, and variability
   - G. equipment and layout.
2. To sift out that part of the information which is pertinent and record it in usable form.
3. To gather together as many potential ideas for improvement as possible:
   - A. from the people interviewed
   - B. by analysis of the information collected and by application of the principles of system and procedure design and motion study
   - C. from other system improvement studies
   - D. from outside sources—other companies and available literature.

4.1 GATHER INFORMATION BY INTERVIEW AND OBSERVATION

The first step is to determine the general scheme of the system, who are involved, where they are located, and what forms are used. At this point it is helpful to review existing organization charts, manuals, procedure instructions, reports, and data from the forms control records. Then, by personal interview and observation, find out what each person does, and when, how, and why. If this is done in a thorough and orderly way, and if sufficiently detailed and accurate

* There is always a tendency to underestimate the number of man hours required to make a reasonably good system study. This is particularly true if the person making the estimate is not the person who will make the study.

† The following articles on system analysis, design, and improvement are presented in terms of studies covering systems of moderate complexity. For smaller parts of the system, the same principles and techniques are valid, but their application is considerably simpler than indicated here.

notes are made, it should be possible to construct from this person-by-person data a complete picture of the flow of information and the sequence of events in the system cycle.

4.1.1 Arrange interviews in organizational sequence. In each department, it is both proper and efficient to start at the top and work down the organizational ladder. Thus each introductory contact is made with knowledge of at least the person's name, title, and general duties, and there is no violation of protocol. Where there are a good number of people under one supervisor, and personal introductions would be inconvenient, it is often helpful to make a rough layout sketch of the area and to note the necessary information about each person in the rectangle representing his desk or work station. It may also be a good idea to sketch an organization chart of the department if it includes several supervisors and/or group leaders. By progressing down the organizational chain, the harvesting of information proceeds in an analytical pattern from the general plan to the routine work—from the fundamentals to the details. The relationships between the various activities are determined first. Thus the more specific knowledge is readily understood and categorized. Questions are more pertinent and well put, and important factors are less likely to be overlooked. Also, the supervisors' explanations of policies, special terminologies, technical matters, personnel problems, operating problems, and other background items are obtained early enough to be helpful in planning and conducting the study.

Some supervisors prefer to go into considerable detail in explaining the workings of their part of the system. This is helpful, but it does not reduce the importance of interviewing the people who actually do the work. Inevitably there are many discrepancies between what the supervisor believes is being done and what is actually going on. This is simply a reflection of the fact that the only person who is really up-to-date about what is done, and how it is done, is the person who is doing the job every day.

4.1.2 Interview technique suggestions. The manner in which the interviews are conducted is extremely important. Although space does not permit an adequate discussion of this topic,* a few elementary suggestions are as follows:

1. Be patient, pleasant, and courteous.
2. Speak the language of the system.
3. Ask definite, objective questions.
4. Be thorough, but stay within the person's area of responsibility and factual knowledge.
5. Encourage questions and suggestions.
6. Avoid proffering your own ideas and opinions.
7. Make no promises, and give no instructions.
8. Avoid implied criticisms of methods, procedures, people, or policies.

4.2 AT EACH WORK STATION, OBTAIN AND RECORD ADEQUATE INFORMATION

The objective should be to obtain all the pertinent information at one interview. It is not enough to ask the person to explain in detail what he does and how he does it. Very few people are able to give a comprehensive, well-organized summary of the tasks they perform without considerable help in the form of directed questioning. Also, of course, the person doing the job cannot be expected to know the kinds of information needed, and seldom realizes the importance of details. If the person has been on the job for some time, it is usually necessary to watch him perform each task in order to find out what he actually does.

Complete and legible notes must be taken, and they should be recapped promptly. It is difficult to remember fragments of information which were not

* See Neuschel, *Streamlining Business Procedures*, pp. 161-62; also Ross, *Technique of Systems and Procedures*, Chapters III and IV, particularly pp. 105-109 and 115-121.

written down or to decipher interview notes two or three days old. For obvious reasons, it is undesirable to ask the same questions twice.

4.2.1 Obtain copies of all documents. For each document received, kept, or originated at the work station, acquire at least two copies (or sets). One copy is for a reference file or "morgue"; the other is for use in discussion and note taking. This second copy should be filled out with typical data.

4.2.2 Information to be obtained

1. *For each task performed* at the work station, find out:

A. When it is done, how often, and how it gets started.

B. What the task consists of—and how it is done—a step-by-step description of the work and the methods.

C. How much time it takes—per day, week, or month, and also per unit of work. Obtain not only an average or typical figure, but also estimates of maximum and minimum time.

D. The customs and rules followed in interpreting information and making decisions between alternative courses of action.

It is also important to know the reasons for each element of each task performed. If not obvious, or previously determined, this can sometimes be determined by discreet questioning of the operator or clerk. However, it is often necessary, or better, to obtain this information elsewhere.

2. *For each transmittal* received* at the work station find out:

A. When and how received, and from where or whom.

B. How many received at a time; how many per day or week.

C. Information checked, deleted, used, and/or posted to a record, work sheet, or another transmittal.

D. Typical errors and omissions found, their frequency and seriousness, and the corrective action taken.

E. Information added, including check marks, signature, date, rubber stamps, marginal notes.

F. Handling and ultimate disposition of all copies.

3. *For each record kept* at the work station, determine:

A. Information posted—definition and source of each item, how posting is initiated, and frequency of posting.

B. Methods of posting and filing, time required, and equipment used. Also, where, when, and how individual sheets or cards are originated.

C. Information checked, deleted, used, referred to, summarized, posted to other documents, or reported orally, and frequency, method, purpose, and time required for each operation.

D. Retention time and ultimate disposition of all copies.

4. *For each transmittal originated* at the work station, find out:

A. When originated, how often, and how origin is initiated.

B. How compiled or filled out, reproduced, sorted, checked, and so forth, and time required for each operation.

C. Information transmitted and the source and/or derivation of each item.

D. Purposes and uses of each copy and its destination or routing.

E. Errors and omissions referred back to this work station—nature, frequency, and corrective action required.

5. *For each item of equipment* at the work station, determine:

A. Identification and description (and possibly the floor plan layout).

B. Uses—applications in this and other systems.

C. Work load—amount of use and breakdown by classes of work.

D. Capability—capacities, speed, and other operating data.

4.2.3 Probe for latent information and ideas. Generally, the analyst will know in advance the major tasks performed at the work station with respect to this system. But, almost invariably, there are numerous supplementary tasks of which he is not aware. It is often very worth while to ask specifically about the things listed below.

1. Periodic tasks—those which must

* *Transmittal* is used to denote one or more items of information sent at one time on a document (form or otherwise) or by any other means.

be done only at certain dates or every so often, as necessary.

2. Special jobs and fill-in work; special requests for information.

3. "Reference" files and "dead" files, log books and notebooks, and other records not used in the normal run of work.

Such probing frequently turns up unnecessary work, duplications of records, and tasks which are being done at the wrong work station.

It is also a good idea to ask about special problems encountered at the work station, such as wrong information received, incomplete information, special cases the procedures do not cover, work load lulls and peaks, criticisms received concerning quality of work, difficulty in meeting deadlines, and interruptions. And, of course, all kinds of ideas and suggestions that might lead to improvements should be solicited. One way to bring out ideas is to encourage the person to ask questions. In fact, one of the important results of skillful and enthusiastic interviewing is developing the questioning, improvement-seeking, point of view in the administrative personnel.

4.3 SUMMARIZE THE GENERAL INFORMATION COLLECTED

The information collected by observation and interview at the various work stations, and from other sources, must be analyzed, sorted, and summarized in various ways. For a given system study, some or all the following types of summaries may be worth while, particularly the first two.

1. *System functions and benefits.* This should be an outline of the administrative functions the system is supposed to serve, supplemented with a listing of the ways in which the system is expected to achieve savings for the company. It should include notations to indicate the extent to which the present system serves its purposes and produces actual benefits.

2. *Ideas for improvement.* Summarize ideas obtained from the system personnel and derived by the analyst during the investigation. Record the source of each idea.

3. *Special requirements for the system.* This should be a simple list of specific requirements, such as deadlines and urgencies, relative accuracy and completeness of information produced, legal requirements, and special demands of superior and related systems.

4. *Special limitations imposed on the system.* Include any unusual restrictions with respect to such things as personnel, organization, and acquisition of equipment, and also inherent weaknesses in supporting systems which cannot be corrected immediately.

5. *Technical information.* Clarify notes on such things as the mathematics of calculations made and statistical parameters used, principles of machine and equipment operation, and definition and usage of special terminologies.

6. *Basic work load data.* Recap pertinent data, such as sales analysis, product breakdown, and employment figures.

7. *Major policies.* Outline those policies affecting or controlling the procedures and the important decisions.

4.4 ANALYZE THE RESPONSIBILITY DISTRIBUTION

A written analysis of the distribution of responsibilities for system functions among the various organizational units is often valuable. It is not uncommon to find important responsibilities which are not clearly assigned, responsibilities which are unaccompanied by authority, responsibilities which are duplicated or overlapped, and responsibilities which are poorly placed. A simple way to summarize the existing distribution of responsibilities is to list all departments or groups participating in the system and then to write a brief description of the tasks and duties for which each is accountable. A word of warning—it is easy to make assumptions here which are either false or only half true. Responsibilities are not always

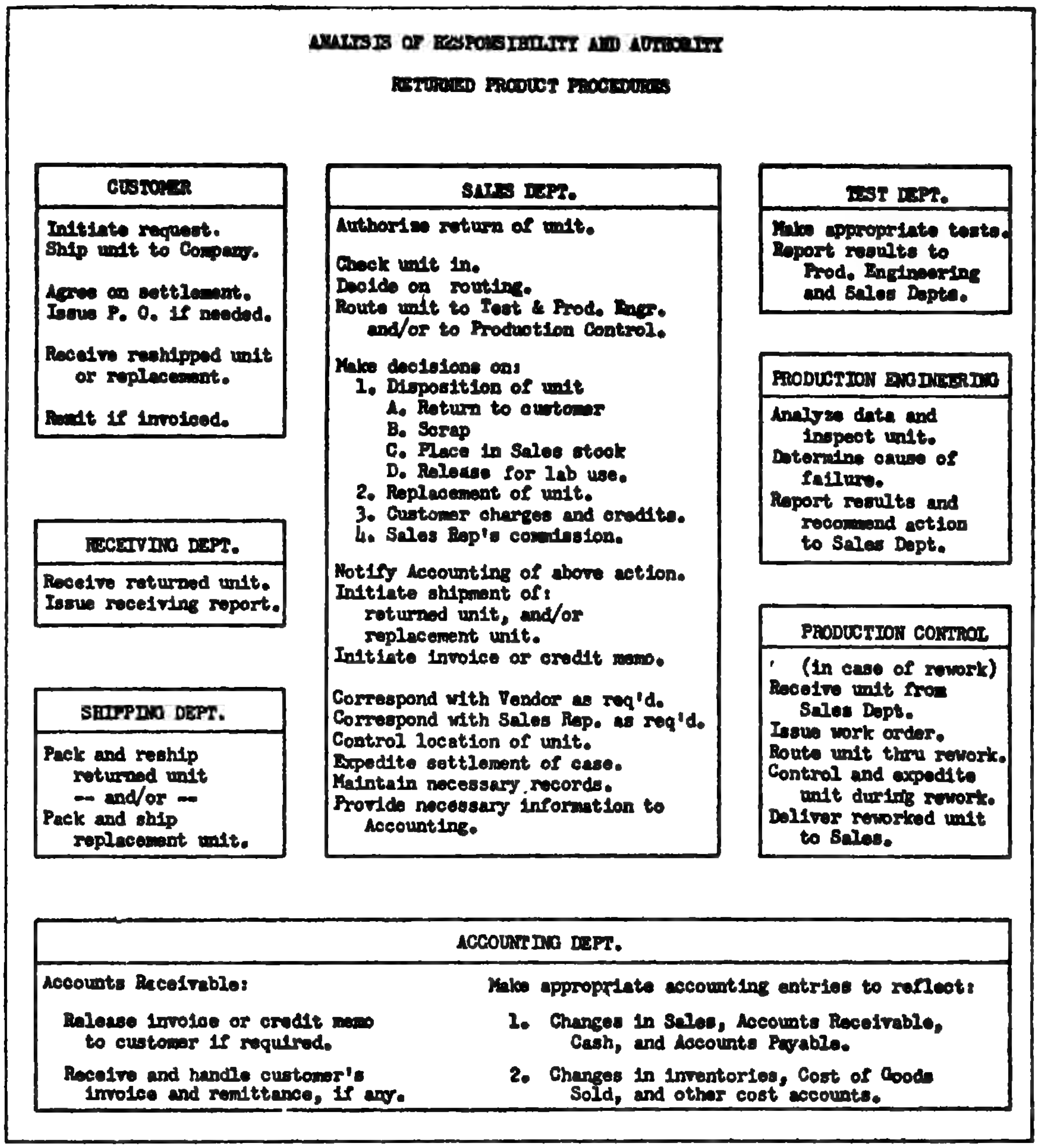


FIG. **6.5** A RESPONSIBILITY CHART OF A SIMPLE SYSTEM.

found to be where they were originally assigned, or where managers think they are. To be truly and firmly placed, a responsibility must not only be assigned, but must also be accepted and carried.

A *responsibility chart* is a good way to present this analysis in a clear and compact manner in order to discuss it with supervisors and managers. Figure 6.5 is an example of how this can be done.

If the analysis of responsibilities is properly drawn up, it will not only point up basic deficiencies, but will also give a complete functional description of the system broken down by departments.

4.5 ANALYZE THE FLOW OF ITEMS AND FORMS

For most system studies, the most useful and productive analysis is of the flow of the documents* and the items which the system controls or

* Or other devices for transmitting information—see Art. 12.

processes. The general technique is to describe the system as an administrative process consisting of interconnected sequences of operations, transportations, and storages. This should be done in such a way as to show all the necessary tasks in proper sequence, and all the information transmittals and storages, in relation to the movements and storages of each successive item or case processed through the system.

A system flow analysis may be written, tabulated on a form, or diagrammed. In general, a chart of some kind is a more satisfactory means of summarizing and analyzing the system flow and function than a written description. The use of symbols and lines instead of words makes it possible to bring together the complete operational structure of the system in a compact form. This is useful not only for reference and discussion, but also for bringing out deficiencies and opportunities for improvement. Subsequently, a chart of the present system is often useful in explaining the advantages of proposed changes.

4.5.1 How to chart the system flow. There are many ways to draw a chart of the system transmittals and activities. The manner in which this is done and the time spent on it should be whatever is appropriate for the particular system and the people involved in the study. Brief descriptions of four types of system flow charts follow this paragraph. All these charts show *sequence* and *flow*, in different ways. Each also is designed to show certain other relationships and information. Any one, or perhaps two, may be very worth while, depending on the nature and complexity of the system and the specific objectives of the study.

Each document should be traced from origin to final disposition. Each item controlled by the system should be traced from its entry to its exit from the system (or through a complete cycle if recirculated). This provides a check on the completeness of the information collected and also shows up pointless terminal storages, duplications of records, and other possibilities for improvement.

In general, any chart of the present system is a working paper, not a formal presentation. Fine art work is not necessary; free-hand sketches are good enough. On any one chart, and within any one company, consistency in the charting conventions has some advantages. But strict adherence to standard rules and symbols focuses attention on drawing the chart rather than thinking about the facts being recorded and the possibilities for improvement. Some innovation and imagination is called for to fit the technique to the situation and to summarize the data collected in the most useful ways.

4.5.2 Types of sequence-flow charts. Four types of charts are described below to show some of the different techniques and possibilities. The examples referred to are from systems which are fairly well designed. Consequently, the figures illustrate how sequence-flow charts can be drawn and what they show, but they do not demonstrate the ways in which they point up system deficiencies.

1. *Simple sequence diagram.* Shows the sequence of tasks (operations), information transmittals, item transportations, and storages (those not terminated until a certain time arrives or a certain event transpires), and indicates relationships between sequences. Usually carries selected explanatory explanation on the diagram and/or in footnotes. Examples: Figs. 6.6 and 6.7.

2. *Interdepartment flow diagram.* Similar to a simple sequence diagram except operations and storages are grouped in columns or blocks by organizational units. Example: Fig. 6.2.

3. *Travel diagram.* A specialized chart aimed at pointing up unnecessary travel (number of moves and distances), backtracking, and tortuous flow patterns. Shows sequence of events and can carry same data as a simple sequence diagram. Special feature: indicates travel routes, relative locations, and distances, usually on a scaled layout sketch. For examples of this type of chart, see Section 8.

4. *Time diagram.* Useful for cyclical procedures where the same sequence of events is repeated for the same or suc-

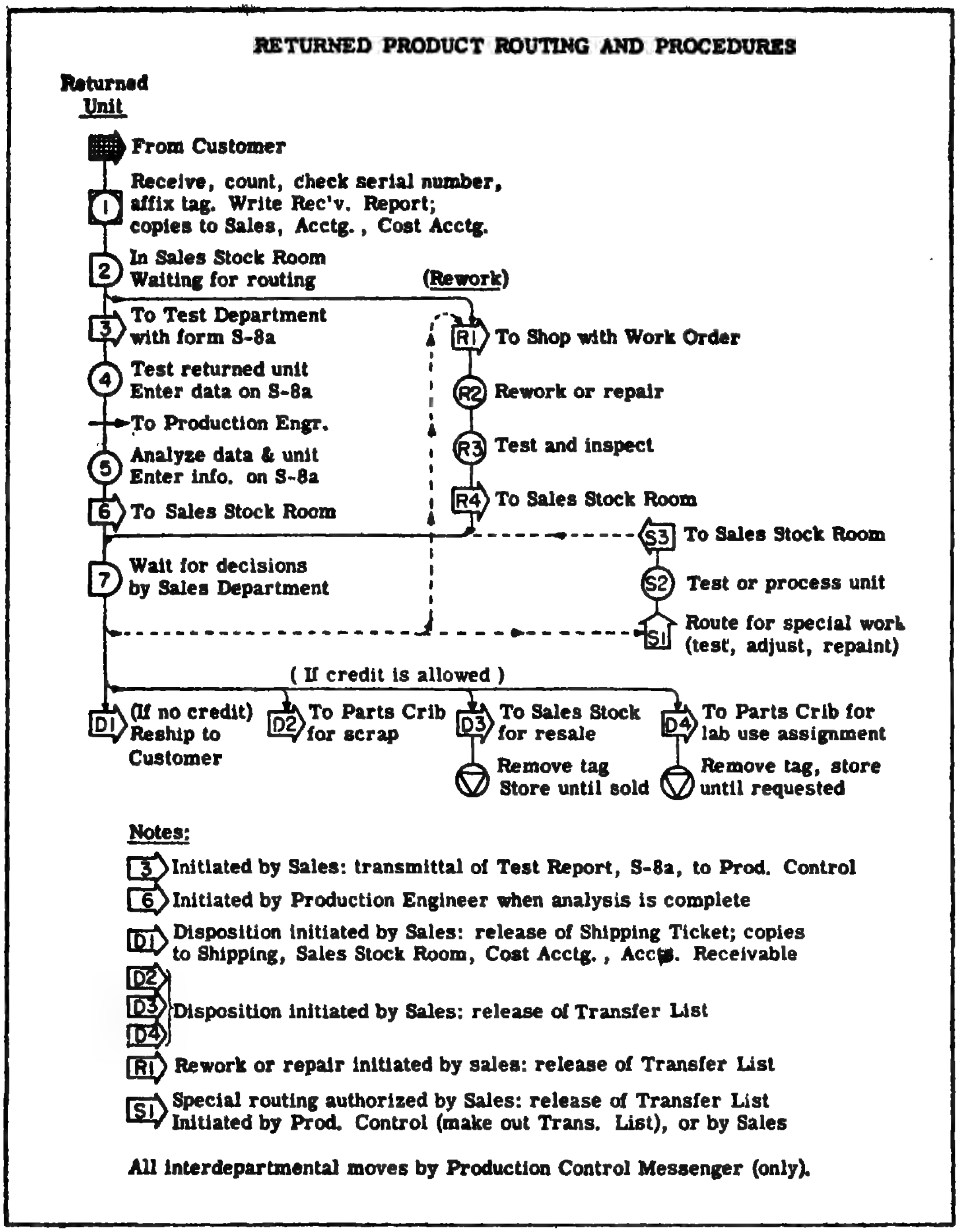


FIG. 6.6 A SEQUENCE DIAGRAM SHOWING THE BASIC PLAN OF THE SYSTEM DESCRIBED IN FIG. 6.5. THE FLOW ITEM CHOSEN FOR THIS CHART IS THE SOLD PRODUCT UNIT RETURNED BY THE CUSTOMER FOR REPAIR OF CREDIT.

cessive items processed. Special feature: the elements of the cycle are laid out on a time scale, usually along the vertical dimension of the chart. Points up delays and often indicates ways to shorten the system cycle. Example: Fig. 6.8.

There are a number of charts used in system analysis which are somewhat different from the four types described above, as well as many variations of

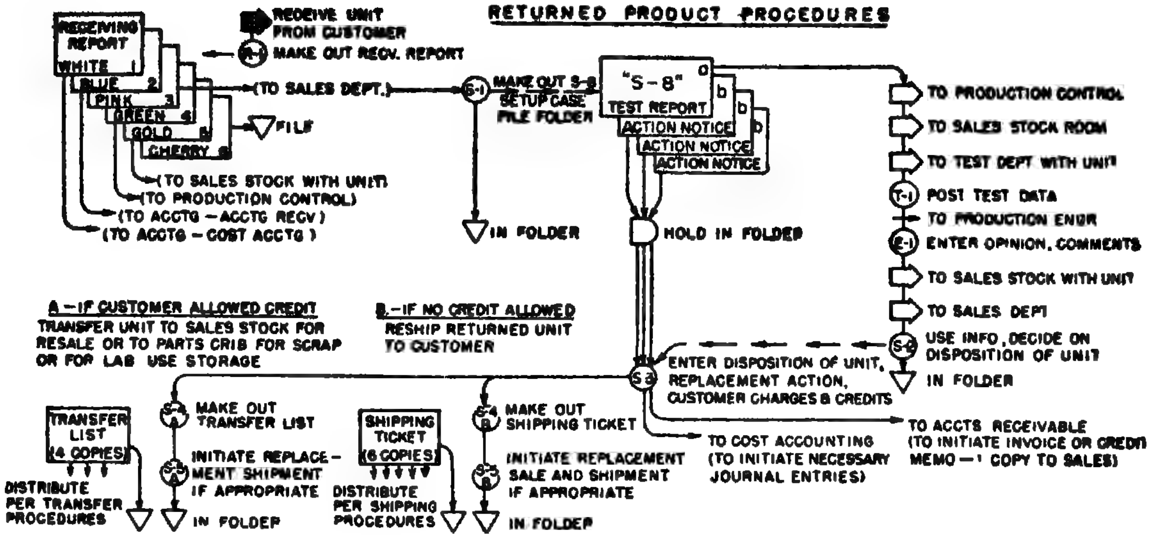


FIG. 6.7 A SEQUENCE DIAGRAM SHOWING THE FLOW OF KEY ITEMS OF PAPERWORK IN THE SYSTEM ILLUSTRATED IN FIG. 6.5 AND 6.6.

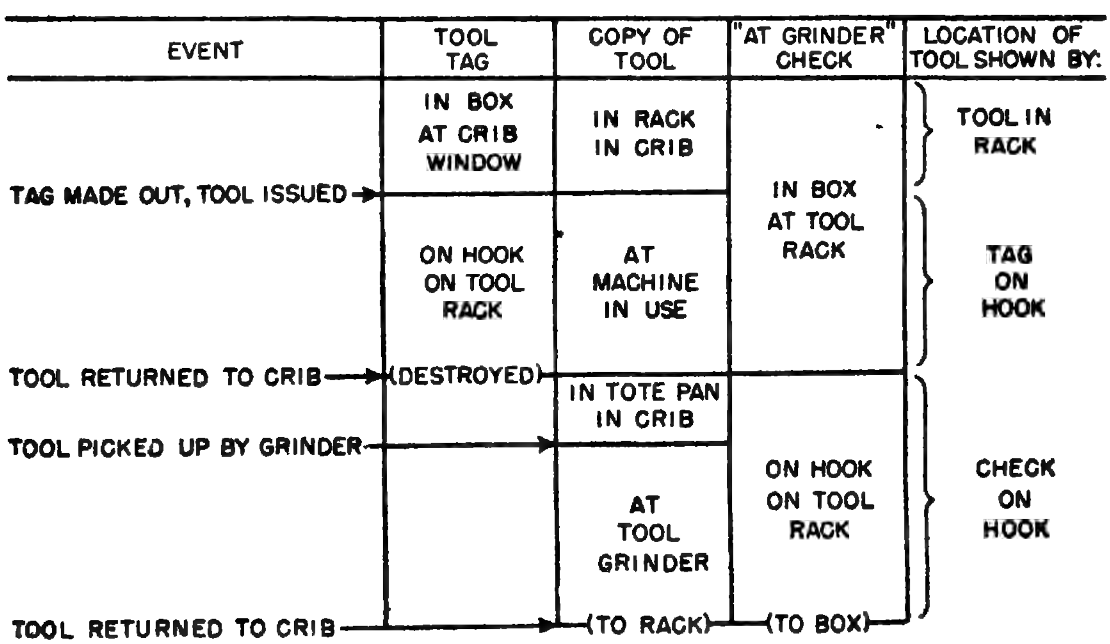
these four.* There are also innumerable different sets of symbols and conventions. In general, the design of the chart and the details of its construction are not important if it tells the whole story and brings out clearly the types of deficiencies it was intended to show.

*See Section 5, pages 317-342; also Norman N. Barish, *Systems Analysis* (New York: Funk & Wagnalls Co., 1951), Chapter V; and Neuschel, *Streamlining Business Procedures*, pp. 146-159, 312-313.

4.6 ANALYZE THE SYSTEM INFORMATION

Analysis of a system is not complete without an item-by-item review of the information it receives, processes, stores, and produces. The ob-

FIG. 6.8. ONE CYCLE OF TOOL SUPPLY SYSTEM OF EXAMPLE 1 (ART. 1.4).



jectives are to find out just what information is needed and why and to discover possibilities for eliminating unnecessary information, extra work, and opportunities for errors.

The importance of a detailed information study depends on the volume of work handled by the system. For example, consider a travel expense reimbursement procedure. If there are 100 reports per year, a little extra information on each report is of little real consequence. For comparison, consider a daily time report procedure covering 400 employees. If they average five jobs per day, each item of information required per job is written, checked, and tabulated more than half a million times per year. Extraneous, vague, or poorly defined items of information become expensive in a case like this.

4.6.1 Information flow study. One general way to analyze system information is to trace the flow of each item from its origin to its final disposition and to determine its definition, source, derivation, frequency, recordings, transmittals, storages, transcriptions, verifications, and uses. To do this systematically, it is necessary to classify all the items of information handled in a system so that none are overlooked and so the analysis can be carried out in an orderly manner. Theoretically, the best classification would be by type of information. This would bring together similar items of information and help to make duplications and redundancies apparent. A more practical classification is by transmittals and storages. In most systems, nearly all the information is transmitted and stored in written form. Therefore, a natural grouping is by the documents on which it is recorded.

For each document, complete notes covering each item of information can be made on or attached to the sample copy. Then, by studying these sample documents, together with the paperwork flow diagram, the system information can be reviewed rapidly and thoroughly. Notes should be taken of the following things:

1. Transcriptions of information from one form to another. These represent error opportunities as well as clerical work.

2. Duplications and redundancies of information recorded on different transmittal and record documents in concurrent use. These point out opportunities for eliminating and combining documents.

3. Items of information whose definition and meaning are not clear, including derived statistics (such as averages) and reported items whose titles or descriptions are indefinite or ambiguous. These often lead to discovery of incorrect and inappropriate uses of information.

It may be necessary to make a supplementary study of items of information used in a system which are not recorded in writing, such as those transmitted by voice or obtained by observation. This is likely to become more and more important as electronic and mechanical devices for handling spoken and coded information become more prominent in the field of administrative systems.

4.6.2 Input-output analysis. Another way to analyze the information is to break the system into segments by tasks, locations, or organizational units and to study the flow of information into and out of each segment. The essential idea here is to isolate an area of administrative activity and make an item-by-item review of the input and output of repetitive information. This concept is particularly helpful in the analysis of systems utilizing data-processing equipment, such as punched card machines.

An input-output analysis can readily be made for each work station, or for each task performed at each work station, from the interview data. For each item of input, determine its source and definition and how it is received, recorded, checked, stored, and used. For each item of output, determine the immediate source or derivation, the frequency produced, the destinations and purposes, and how and when it is recorded, checked, and transmitted.

If the items of input and output are

listed by type of information, duplications and redundancies will stand out. And, if each item is reviewed with respect to purpose and manner of statement, it is often possible to eliminate or combine some of them and reduce others to more concise form. Also, comparison of the input-output analyses of different work centers, procedures, or systems is likely to reveal overlapping functions, poor placement of responsibilities, and lack of coordination.

4.7 OTHER TECHNIQUES OF ANALYSIS

There are numerous methods of system analysis covering a wide range of specific objectives. Some of these have been published; many have not. The general types of analysis described in the preceding paragraphs are aimed, in general, at improving the basic system process with respect to effectiveness and cost. The motion study techniques they employ are those for process analysis and improvement.

Analysis of the work methods used to perform the various system tasks is basically the same problem as analysis of factory operations. Here the more refined techniques of motion analysis and time analysis and the principles of motion economy can be profitably applied.*

Another technique is the analysis of administrative activities by organizational groups—sections and departments. This is particularly effective for developing inter-system coordination and obtaining information with which to plan an integrated system study program. The results of this type of analysis may be summarized in a work distribution or activity analysis chart.† This type of chart usually breaks down the activities of each person or work station in detail and shows an estimated distribution of the working time among these activities

* See Section 5; also Barish, *Systems Analysis*, Chapter VII.

† See Neuschel, *op. cit.*, pp. 154-57. Also Barish, *Systems Analysis*, pp. 74-87.

If one of the specific objectives of the study is to improve the physical arrangement and location of one or more work areas, plant layout analysis methods (such as the travel diagram) may be an important part of the system analysis.*

Sampling techniques and methods of statistical analysis are often very valuable in studying systems which depend on, or process, numerical data. In some cases, effective application of statistical methods is essential for analysis and improvement.

5. SYSTEM DESIGN—PLANNING AND DEVELOPMENT

This article is concerned with the practical question of how to develop a better system. As far as possible, principles and refinements of system design are deferred to Arts. 6, 7, and 8. The objective here is to devise alternatives, to choose between these alternatives, and to prepare recommendations.

Having analyzed the present system, a general decision must be made about the scope and extent of change contemplated. Shall the basic plan of the system be retained, or should it be completely overhauled? Factors to be considered are: the time and man power available for the job, the potential increase in benefits and decrease in cost, and the probabilities of acceptance of recommendations affecting different divisions and departments. Although it is essential to take the point of view that there is nothing sacred about the present system or any of its parts, it is also important to keep in mind that there is no point in developing recommendations that cannot be sold, or in making changes that do not clearly benefit the company in the long run.

This article deals in terms of building a new system from the bottom up. If the situation calls for less drastic action,

* For techniques and principles of layout analysis and improvement, see Section 8. Also Barish, *Systems Analysis*, Chapter VI.

as is frequently the case, many of the steps outlined below can be shortened, combined, or omitted.

5.1 DEVELOP BASIC PLANS

The first step in designing the system should be to state roughly the objectives to be achieved with respect to costs and benefits.

Cost reduction objectives can be formulated by reviewing the methods and procedures improvement ideas obtained thus far, evaluating the potential of each, and arranging them in possible combinations. Then the important goals of redesign, such as a reduction of work force, elimination of overtime, or the release of time for more productive use can be established.

Objectives relating to the effectiveness of the system can be formulated by reviewing its purposes in terms of the actual benefits it can produce and outlining the fundamental actions necessary to obtain those benefits. This helps to confine the new system to the functions it is intended to cover and to focus attention on critical procedures. For instance, in planning the system of Example I (Art. 1.4), the following things were seen to be necessary in order to secure the desired benefits:

1. All carbide-tipped and special form tool bits must be sharpened properly and in accordance with standard specifications. This requires suitable equipment, adequate skills, and centralization of the work.

2. Sharp tool bits must be available when needed, but the stock must not be excessive. Therefore, tool bits must be placed under a tool crib control designed to assure their prompt return and sharpening, to initiate correction of errors and violations, and to accommodate changes in tool usage.

If the design objectives are clearly thought out, the task of working out the best methods and procedures is greatly simplified. The purposes of this first step are to define in practical and definite terms what the system must do, what is essential, and, hence, the basic plan of the system.

5.2 PLAN THE ASSIGNMENT OF RESPONSIBILITIES

The next problem is to allocate the functional responsibilities in the best way, considering the existing organization plan, economy of time and money, and the operating effectiveness of the system. Clearly, any distribution of the system responsibilities is necessarily a compromise. It is not possible to minimize cost and time, maximize benefits, and conform to a precise organization theory all at the same time. Consequently, any set of rules, such as those which follow, are inherently in conflict with one another because they affect different variables of a complex problem.

5.2.1 Some rules for assigning system responsibilities.

1. *Assign system tasks to groups having suitable equipment and personnel.* Consider job skills, knowledge, and rates of pay. Attempt to utilize free time and to balance work loads. Frequently it is best to place tasks according to type of work rather than on the basis of function or purpose. Minimize the number of departments involved. Place sequences of tasks in the same location if practicable.

2. *Make the same person or group responsible for similar and related decisions.* Consider work loads, rates of pay, and availability, as well as qualifications of the personnel. Delegate routine decisions to specialists rather than to supervisors and technicians. The objective is reliable, consistent, and speedy decisions at the least cost.

3. *A control or follow-up responsibility should be placed in the department most concerned about the results and least influenced by the department responsible for the performance of the function being controlled.* This is necessary to avoid bias in action or reporting, or lack of interest, either of which would impair the effectiveness of the control

mechanisms. For example, location control of capital equipment is likely to be more effective if placed with the group responsible for plant layout rather than with the accounting department. Or, the follow-up to obtain decisions about rejected products returned by customers should be the responsibility of sales rather than inspection.

5.2.2 Adjustments in organization may be necessary. Frequently, important system improvements are not feasible without transferring people from one supervision group to another concurrently with reallocation of responsibilities. For example, to reduce the cost and improve the effectiveness of a quality control system, it may be necessary to centralize the accumulation, analysis, and reporting of quality information. Such work is often scattered through various groups with little coordination and considerable duplication. By focusing the responsibility for such a function on one group of people brought together under common supervision, it is often possible for two people to do the work of three, or three to do the work of four, and to do it more effectively.

5.3 CORRECT DEFICIENCIES IN POLICY

In most system design projects, four common kinds of policy problems can be expected:

1. Policies which are not clearly formulated, and are therefore applied inconsistently or changed whenever convenient.

2. Departmental policies which directly conflict with those of another department.

3. Policies which are wasteful or expensive to follow.

4. Policies which are not, or cannot be, enforced.

These policy problems and questions should be cleared up as soon as they are encountered. Otherwise, much detailed planning of procedures, methods, and forms may have to be done over again. For instance, the system of Example II (Art. 1.4) depends heavily on the decision that the vendors' invoices may be paid before inspection is completed. Other policies which affected the design of this system ranged from questions concerning vendor contact and relations to whether or not a hand-written shipping-ticket-debit-memo would be permissible.

Many systems and procedures are purely a means of implementing and enforcing policies. These range from such simple matters as visitor control and the use of company cars, through problems of security and public relations, to complex things like incentive wage systems. Clearly, in cases like these, the policy should be formulated and approved before the system is designed.

In other systems, policy questions may be encountered with respect to details of method and information. For example, should money amounts be entered to the nearest penny or nearest dollar? Should requisitions be written for items of small value? Should a work request be approved at the supervisor level, department head level, or division head level? It is usually wise to obtain prior agreement if changes in such things are to be incorporated in the new system.

5.4 PLAN THE PROCEDURES AND FLOW OF INFORMATION

If the design objectives, responsibility distribution, and basic policies have been established, the foundation and general structure of the system are determined. The next step is to plan the operation of the system in terms of procedures and flow of information.

5.4.1 A suggested plan of attack. The best approach is to make a rough freehand sketch of the flow of necessary information and then proceed to revise it and improve it until a fully satisfactory scheme emerges. In doing this, the analysis notes will supply the data and the responsibility distribution will serve as a guide. At this stage of design, the system information, procedures, meth-

ods, and forms are treated in general terms; their detailed design should be deferred until the framework of information flow is completed.

5.4.2 Provide a complete set of plans. Clearly, the better a system is planned, the more different cases and problems it will handle without improvising and the greater will be the benefits of planning—speed, coordination, effective use of time and effort, economy of supervisory and executive time, consistency of decisions, and reliability of information. It is necessary to anticipate all the different cases falling within the range of application of a system, and the important variations and special circumstances which may arise. For instance, in any system dealing with successive lots of parts, such as Example II, it is usually necessary to provide for splitting a lot into two or more parts for scheduling reasons, reworking rejected parts, or special diversion or processing of part of a lot. In Example I, it was necessary to provide for such eventualities as experimental tools, new standard tools, and increasing or decreasing the stock quantity of a standard tool. In a payroll system, it is necessary to provide for special deductions, salary advances, and employee terminations, as well as new hires, transfers, changes of rate, and numerous other things.

In planning a system, it is usually best to sketch out the plan for the normal routine first, and avoid the side tracks which must be provided for variations and special events. However, these must be kept in mind, because they usually affect the main-line procedures.

5.4.3 Plan the forms and their use. Planning the flow of information and the procedures inherently involves planning the documents needed and how they will be used. In general, the number of forms and the number of copies of each should be minimized Wherever possible, the forms of other systems from which and to which information flows should be utilized in place of new forms.

Each copy of each document originated and/or handled in the system should serve as many purposes as practicable, and its life history should be planned from origin to termination. It is important to provide for the ultimate destruction of each copy when it is no longer worth keeping.

5.4.4 Coordination, consistency, and integration with other systems. Because no one system in a company is completely independent, it is usually true that decisions concerning one system also will affect the cost and effectiveness of other systems.

Coordination with related systems is always important and sometimes vital. For example, a capital equipment acquisition procedure must coordinate functionally with the budget system, the equipment control and maintenance system, the purchasing and receiving system, and numerous accounting procedures. Also, inter-system coordination with respect to time may be important. For example, it is often necessary that reporting periods and cut-off dates of planning, accounting, and control systems be made to coincide, or that daily routines of related systems be closely scheduled to avoid delay and idle time.

Whenever possible, systems requiring similar action in one or more departments should be designed so that the common procedures are similar if not identical. For example, the production control procedures for experimental production lots should be consistent with those for other work-in-process. Or, the receiving department procedures should follow the same pattern for all classes of items received. The advantage of consistent procedures lies in standardization, which permits rapid automatic processing with a minimum of questions and decisions and gives greater assurance of correct results for all cases.

Integration between systems is accomplished by devising multi-purpose procedures, records, and reports. In general, these represent duplications eliminated or avoided. Such possibilities are obvious when the systems are interdependent, as in purchasing, receiving, controlling, issuing, and accounting for materials and parts. They are not

so obvious between systems such as in-process quality control and production control, design control and production planning, and tool control and methods control.

5.5 DESIGN AND PHYSICAL SYSTEM

Having answered the questions *what, where, when, why,* and *who,* about the system, the question still remains, *How* will the work be accomplished? The answer to this consists of three interrelated parts: selecting suitable machines and equipment, designing the forms and reports, and planning the work methods.

5.5.1 Select the system methods and devices. Usually there are many possible methods and labor-saving devices which should be considered (see Art. 12). The problem is to select the combination which will minimize the costs of labor, supplies, and equipment. All reasonable alternatives should be considered. This requires not only a review of commercially available equipment, but also some thought about the possibility of designing and building special-purpose equipment. Of course, preference should be given to equipment already on hand. If the system involves a large volume of repetitive work, a choice of equipment may have been made earlier in the project and need only be reviewed for cost justification of this point.

Comparing the costs of alternative equipment necessarily requires planning and evaluating the related work methods and forms.

5.5.2 Design the forms and reports. The decisions to be made for each document fall into three classifications:

1. *Type of document.* The main factors which affect the type of document are the number of copies, the rate of use, and (therefore) the method of writing and/or reproduction.

2. *Specifications.* Decisions must be made concerning the size, type of paper, and numerous details, such as punching and binding.

3. *Layout.* This is a matter of deciding what items of information are to be recorded, the description or instructions for each item, and the arrangement and spacing of the form.

Obviously, the design of the forms should be subordinate to the planned information flow and procedures, and is inherently tied in with the selection of equipment and the determination of work methods. It also requires decisions about the definition, description, and cost justification of each item of information.

5.5.3 Plan the work methods. In order to evaluate the various alternatives of procedure, equipment, and form design, it is necessary to predict the work methods. This requires visualizing just how each task will be done and making a rough estimate of the time it will require. It is then possible to derive a reasonable idea of the cost and work load involved.

If the contemplated work methods appear to be satisfactory, it often pays to check them further by writing brief job instructions. If the system tasks involve a large volume of repetitive work, it may even be worth while to make a formal detailed analysis of the new work methods planned

5.6 IMPROVE THE NEW SYSTEM

There is always room for improvement. This is particularly true of an untested new system which represents a significant departure from the way things have been done in the past. If the system is at all complex, there are bound to be some things neglected, some false assumptions, and some errors in reasoning. Also, there are usually a number of ways to simplify and streamline the system which have been overlooked. Ordinarily, many worth-while changes can be made and occasionally an important improvement.

Analysis notes containing ideas for improvement should be reviewed, and previously discarded alternatives should be reconsidered. The system should be tested with respect to principles of sys-

tem and procedure design (Arts. 6, 7 and 8) and reviewed for new improvement ideas (Art. 9). Also, it may be worth while to apply some of the techniques of analysis (Art. 4) to the new system.

There is, of course, a point of diminishing returns for any improvement effort. However, it is important to correct deficiencies and incorporate as many improvements as possible before submitting the new system for criticism and approval.

5.7 PREPARE DIAGRAMS OR WRITTEN PROCEDURES

There are two main techniques for presenting a proposed new system: written procedures and instructions, and diagrams. Usually, some combination of diagrammed and written explanation is most satisfactory. A diagram has the advantage of presenting a comprehensive summary in a simple way, and can be designed to emphasize important relationships which are likely to get lost in a mass of written words. On the other hand, it is often impossible to convey basic ideas and definitions except in writing.

5.7.1 Charts and diagrams. Any of the types of system analysis charts may be appropriate for presenting the proposed system. The two which are most likely to be useful are the responsibility chart (Fig. 6.5) and the interdepartment flow diagram (Fig. 6.2). If one or both of these types of charts were sketched during the design process, it is a simple matter to redraw them in finished form.

5.7.2 Written procedures and instructions. In place of diagrams, or to supplement them, a written procedure may be desirable. It should include the following:

1. A clear statement of the purpose and scope of the procedure.
2. Key definitions and policy statements.
3. A straightforward summary of departmental responsibilities.
4. An outline of the procedures and how the system works.

Details of methods, forms, and equipment should be omitted from this procedure. It should establish relationships, ideas, definitions, and the general scheme of the system. It should be designed for management-level readers and should be suitable for incorporation in existing standard practice or procedure manuals.

To supplement the manual procedure, and/or the diagrams, it is often necessary to write out detailed instructions for the people who will perform the system tasks and their immediate supervisors. These instructions should explain what is to be done, when it is to be done, and how it should be done. They should establish method as well as local procedure.

For very simple systems, diagrams may not be justified, and the detailed instructions can sometimes be included in the manual procedure without making it over-complicated.

5.7.3 Formal presentation serves two purposes. The obvious reason for preparing the diagrams or written procedures is to make a favorable but honest presentation of the proposed system for review, criticism, and ultimate approval by those concerned and to aid in the installation and subsequent maintenance and enforcement of the new system. A less obvious but equally important purpose is to make a final review and check of the entire system. The process of setting down on paper a full explanation of the proposed system should not merely be an end in itself, but should also serve as a final test and inspection of the system. In general, if the system is difficult to diagram or explain in writing, it will be difficult for the people to learn and follow. Also, it is a common experience to find ends that are dangling, points that have not been covered, definitions that are ambiguous, and numerous fuzzy details that lead to doubt and confusion. It is better to discover and correct these things before presenting the system, if possible, and certainly before installing it.

5.8 OBTAIN SUGGESTIONS AND FINAL APPROVAL

It is usually best to obtain agreement among the supervisors affected before soliciting the approval of managers and executives. This is time consuming, but it has obvious advantages. The supervisors and the people who will do the work are in the best position to detect flaws in the system and deficiencies in the way it is explained. Their questions should be answered and their suggestions incorporated before seeking high-level approval. Also, if they are consulted first, there is likely to be little resistance to the installation and enforcement of the new system.

It is usually cheaper and more satisfactory to obtain at least tentative agreement and acceptance and to incorporate all worth-while suggestions before installation. This may require compromises as well as acceptance of new ideas. Although it is annoying to rewrite procedures and redraw diagrams at the last minute, this is often less expensive than making changes or reselling the system after it is installed.

6. SYSTEM DESIGN—PROBLEMS AND PRECEPTS

The following is a collection of ideas and suggestions dealing with some of the perennial problems and basic decisions of system design. The objective is to point out some ways of solving these problems and to develop a basis for making certain design decisions. The importance of these topics in a particular project depends on the kind of system being designed and its complexity.

6.1 TERMINOLOGIES

Key terminologies should be carefully chosen and clearly defined. The choice of words and phrases used to denote status or classification or to identify items or documents can be a source of misunderstanding, error, confusion, and inconsistency.

For example, in analyzing the production control and quality control procedures of one company, the adjective "rework" was used to mean four different things. (See Fig. 6.9.) The reasoning behind them, and their relative merits, were as follows:

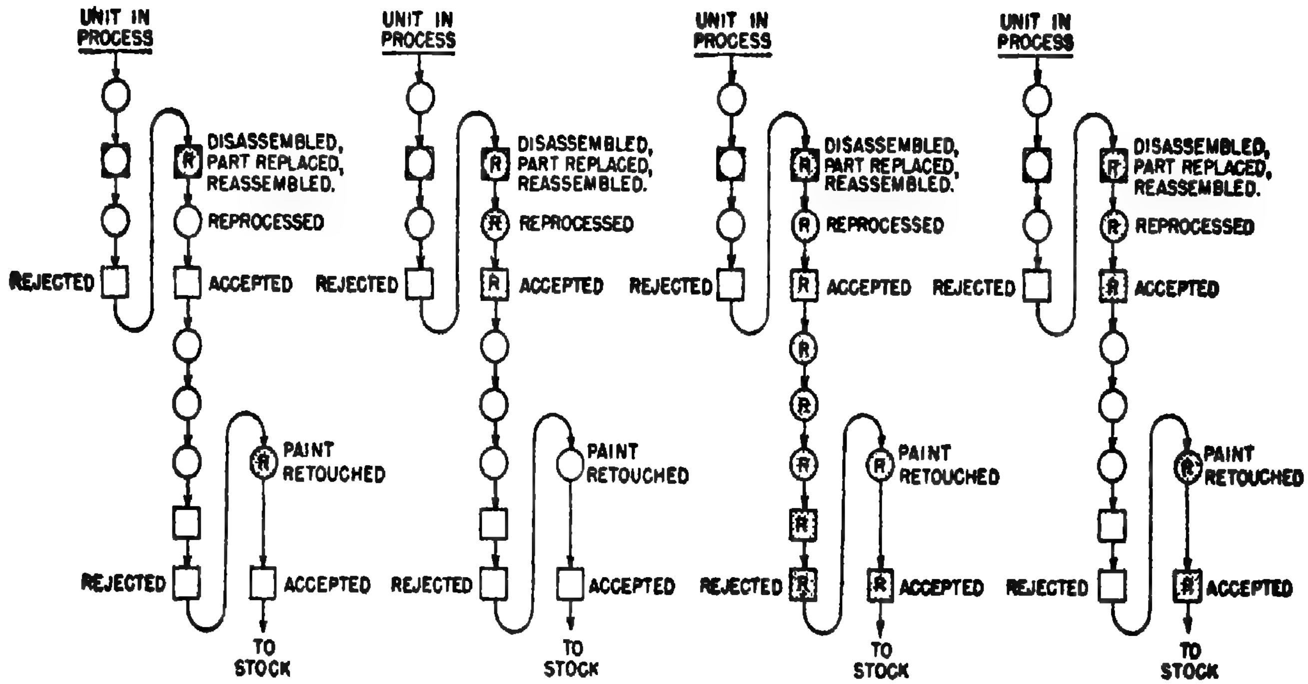
Number 1. Promoted mainly because of the simplicity of record keeping. Not satisfactory because a unit could be recorded as completed new work two or more times at the same work station.

Number 2. Based on the premise that rework should not be recorded unless it is of a serious nature and might affect final quality of the unit. Has same disadvantage as Number 1. Also, creates a further problem of defining "major" and "minor" rework and precludes the possibility of clear-cut standard procedures for handling rework units.

Number 3. Based on the idea that once a unit is rejected, at any point for any cause, it should be identified and treated as a bad-quality suspect thereafter. The proponents also believed the progress and disposition of such units should be recorded separately so the control records would be based entirely on units which were never rejected at all. One weakness is that some units would pass through the process without ever being recorded as good production at one or more work stations. For this and other reasons, various records and reports would be badly biased.

Number 4. The point of view here is that a unit reverts to "new" status, without prejudice, if it successfully passes the original point of rejection after being reworked. Avoids the disadvantages of 1, 2, and 3, and provides a basis for reporting each unit as new work accomplished once, and only once, for each work station it passes through.

The main effects of these four conflicting ideas were misunderstandings between individuals, misinterpretation of reports and records, and misuse of figures transmitted interdepartmentally.



(1) PRODUCT UNIT IDENTIFIED AS "REWORK" ONLY AT FIRST WORK STATION FOLLOWING REJECTION.

(2) UNIT IDENTIFIED AS "REWORK" ONLY IF ITS REPAIR INVOLVES DISASSEMBLY.

(3) IF ONCE REJECTED, UNIT IDENTIFIED AS "REWORK" AT ALL WORK STATIONS THEREAFTER.

(4) UNIT IDENTIFIED AS "REWORK" WHILE CORRECTIVE OR REPEAT WORK IS BEING DONE ON IT.

FIG. **6.9** FOUR USES OF THE TERM "REWORK" APPLIED CONCURRENTLY IN THE SAME COMPANY.

The worst result was that the work-in-process control records and the periodic production and inventory reports were based on the third concept of "rework." But numerous people using this information, including production planning and cost accounting, were interpreting it according to the last concept.

Subsequently, the fourth meaning was agreed upon by all concerned, and the following set of simple definitions was published:

> *New work*—work that is being done for the first time.
>
> *New unit*—a unit at a work station for the first time.
>
> *Rework*—work that is being done over again.
>
> *Rework unit*—a unit in process at a work station it has been through before.

The reporting procedures were then corrected so as to maintain the identity of "rework" units in a systematic way. This made it possible to compute consistent and unbiased planning and control figures (such as per cent rejected and yield factor), to produce inventory and production reports which were meaningful, and to properly segregate the cost of rework from the cost of new work.

Terminologies which are carelessly used in conversation, memoranda, forms, and reports tend to become part of the language of the system. For instance, the term "A.Q.L." means "acceptable quality level," and is an important concept in the field of statistical quality control. Unfortunately, the term is sometimes used in local situations to mean "average quality level," which is quite a different thing. Ordinarily, in cases like this, an attempt to change local custom is not likely to be successful and frequently creates confusion of the type illustrated in the "rework" example. In other words, the theoretical nicety of a terminology and how it is used in other companies is not vitally important if it is used consistently and is universally understood by all those concerned.

6.2 CLASSIFICATIONS

The success of many systems depends heavily on the design of sound plans for classifying the things with which the system deals. This problem of classification involves the systematic segregation of a set of individual things (or cases) into distinct groups according to common characteristics. These groups, or classes, need to be defined and named so as to be logical, useful, and easily understood.

6.2.1 Some rules for classification. For a system of classification to be complete and satisfactory, the following things are necessary:

1. *The total range of individual items to be classified must be clearly defined and limited with respect to kind and characteristics.* (Defining the range of application of the system is the most common problem of this type; see Art. 3.5). Frequently, difficulties of classification can be traced directly to lack of clear definition of the range of items to be classified. For instance, the answer to a question of how to treat units borrowed from work-in-process for special purposes, depends on whether such units should be considered in-process or out-of-process for the purposes of the system. In other words, the first question is, What is work-in-process?

2. *The different classes must be mutually exclusive.* That is, there should be no overlapping, and each individual item to be classified should clearly fall into one and only one group. Ordinarily this means that the basis of classification must be a single characteristic of the items. If it is necessary for all the items within each group to be homogeneous with respect to two or more characteristics, each class must be defined with respect to each characteristic. And this should be done in such a way that an item falling in one class with respect to one characteristic will not also fall in another class with respect to another characteristic.

3. *Jointly, the various classes should cover the defined range.* In other words,

they should comprise a complete set. Thus, any item falling within the range of the classification system must fall into one of the established classes.

In the "rework" case, the classification problem was to establish a breakdown of units-in-process according to quality status and progress. Defining the "rework" status necessarily required naming and defining the "new" status. Then, to complete the classification, a "rejected" status was defined to cover rejected units awaiting disposition as "scrap" (out-of-process) or "rework."

6.2.2 A simple classification problem. In designing a new time reporting and control plan for a production work center, it was found that within a period of one month, ten two-man crews operating four machines ($2\frac{1}{2}$ shifts per day) had reported "idle" time under fifty-six different descriptions. However, they had not reported set-up time, lunch time, and crew time spent on periodic machine servicing, all of which apparently were thrown in with the production time charged to jobs in process. Obviously, to get consistent and reliable time distribution data, a well-planned classification system was necessary. A master system of time classification was devised for all machine production work centers, based on "equipment capacity hours" (24 hours per day, 7 days per week, per machine). The standard breakdown was as follows:

UNSCHEDULED HOURS—No crew on duty at machine.
- Lack of orders.
- No crew available.
- Major repairs.
- Excess capacity.

SCHEDULED HOURS—Crew on duty at machine.
- *Productive Hours*
  - Definition: Machine time employed to accomplish useful work.
  - To be broken down by jobs or classes of product worked on.
- *Unproductive Hours*
  - Necessary work delay—crew performing work necessary for continued operation.
  - Wait for crew—i.e., lunch, first aid or meeting.
  - Service delay—i.e., wait for truck, inspector, or tool.
  - Wait for order—delay due to lack of scheduled work.
  - R & M delay—waiting for maintenance man to arrive or to perform service or make repair.
  - Change set-up—crew changing set-up for new job.
  - Other delay—(Special classifications authorized as necessary).

Working within this framework, a list of authorized standard descriptions for unproductive time was prepared and posted at each production center along with instructions for describing productive jobs. The operator or crew leader was required to report all "scheduled hours" in accordance with the standard instructions and to refer any unusual cases to the shift foreman.

6.2.3 A more difficult classification problem. In a company engaged in research, development, and production of a complex line of equipment, the need became apparent for a system designating the status of each product model with respect to:

1. Placement of responsibility for manufacturing and quality conformance.
2. Type of control over design and manufacturing specifications.
3. Placement of responsibility for development and quality engineering.
4. Performance specifications and warranty status.

In the early stages of developing the necessary planning and coordination procedures, a linear classification system was established based on the concept of a new product proceeding sequentially through four distinct phases from research to standardized mass production. Subsequently, it was found to be difficult to define or determine just when a particular model graduated from one class to the next. Many models appeared to be in two or three classes at the same time. The basic difficulty was that changes in the four general parameters of model progress listed above did not coincide in time. This was particularly true between technical responsibility and manufacturing responsibility.

It was believed that to force coordination of model progress with respect to all four of these factors in a rigid way would make it difficult to telescope the design, quality assurance, and production efforts when necessary and would therefore create undesirable inflexibility. Nevertheless, effective planning and coordination procedures could not be developed without establishing a sound basic plan of product status classification.

To solve this problem, the following reasoning was applied:

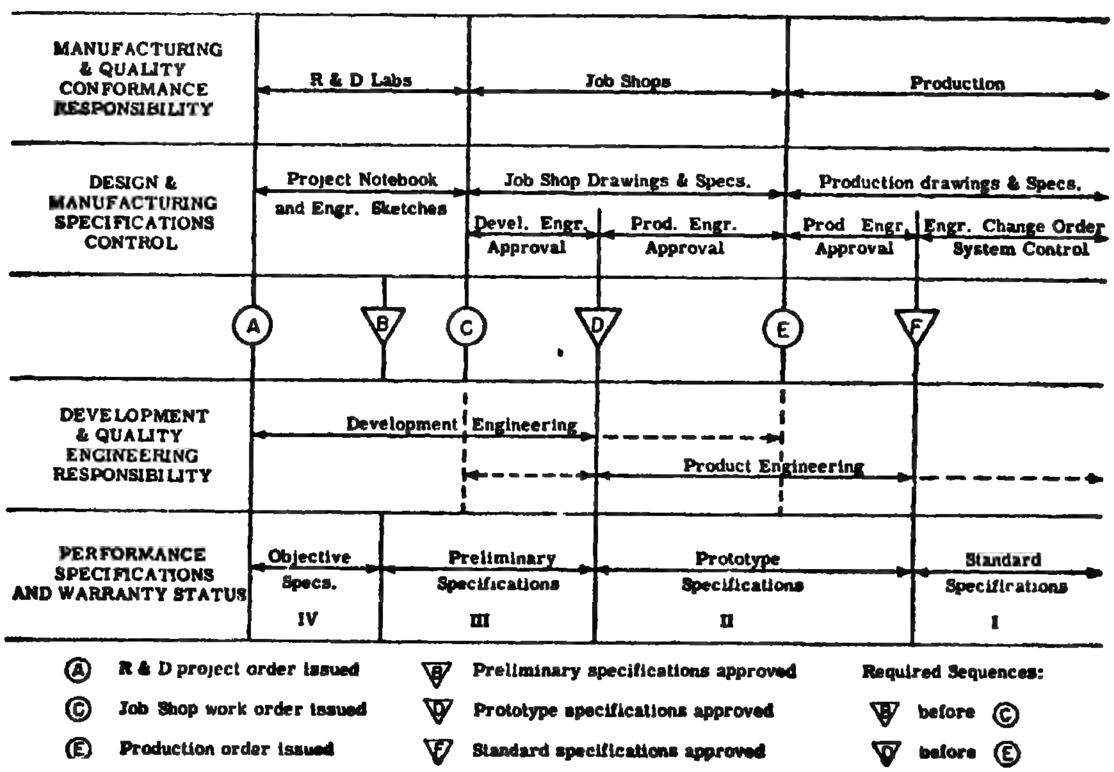
1. Manufacturing responsibility for a product model must be assigned to one of three facilities—research and development laboratories, product engineering job shops, or production. This responsibility should normally be passed from lab to job shop to production.

2. Development and quality engineering is the responsibility of development engineering for a model being built in the laboratories, and of product engineering for a model in production. Transfer of this responsibility from development to product engineering should therefore occur during the job shop manufacturing phase, as soon as prototype performance specifications are approved.

3. Performance specifications and product warranty should progress through four stages: objective (class IV), preliminary (class III), prototype (class II), and standard (class I). Objective specifications should be replaced by preliminary specifications as soon as satisfactory samples are produced. Preliminary specifications should be replaced by prototype specifications as soon as adequate quality assurance is attained. Prototype specifications should become standard and the design should be placed under control of the engineering change order system as soon as sufficient manufacturing experience and quality history have been accumulated in production.

Figure 6.10 is a diagram of the classification plan derived from the above line of reasoning. Note that each product model is to be classified with respect to

FIG. 6.10 A PRODUCT STATUS CLASSIFICATION PROBLEM.



each of the four parameters of progress and status but that the four classification schemes are integrated in suitable ways. However, maximum freedom is allowed in the relative timing of changes in technical and manufacturing status.

It can be seen from this example that whether or not a system is sound and workable may depend very much on the solution of an underlying problem of classification and terminology. Clearly, in this case, the classification plan establishes the nature and basic purposes of the procedures required to attain coordination and control.

6.2.4 Indexing classifications and symbols. A somewhat different type of problem is that of classifying and assigning identification symbols to a large variety of items which must be indexed in a systematic way. This problem is inherent in the design of systems dealing with such things as drawings, tools, capital equipment, accounts, raw materials, forms, employees, and so forth. The problem in these cases is to devise a system of classes and sub-classes into which any present or future item will fit in a logical and definite way and to establish a system of symbols or abbreviations such that each item has a unique identification code. Usually, it is desirable that the symbols should not only identify the items and serve as a basis for indexing the records in a suitable way, but should also provide some descriptive information and/or mnemonic aid.*

Designing an efficient, complete, and durable plan of symbols or codes may be an intricate and difficult task. But the coding scheme is often an important factor affecting the cost and effectiveness of the system. This is particularly true of systems utilizing high speed information processing equipment, such as punched card machines and electronic computers. In general, the coding becomes more important as the variety of items and the frequency of the repetitive system operations become greater.

6.3 TWO PERENNIAL QUESTIONS OF SYSTEM DESIGN

The following are two questions which frequently come up in designing the mechanics of a system.

6.3.1 Standard procedure versus alternative procedures. The same methods and procedures should be employed each time a similar set of circumstances is encountered. But this brings up the question of what shall be considered "similar circumstances."

In general, it is desirable to apply standard methods and procedures to all cases falling within the range of a system. This eliminates the need for choices between alternative courses of action. Thus, wrong choices are avoided along with the time required to make such decisions, and the results are more consistent and predictable. In fact, most of the benefits of administrative systems depend on, or are by-products of, procedural standardization. But this can easily be overdone, and it often is.

Frequently, it is not economical to force all cases through the same procedures. Common evidence of this is the existence of petty cash funds and appropriately simple procedures for handling certain classes of receipts and disbursements, such as purchases and sales involving small amounts of money. Clearly, it does not make sense to require the expenditure of $10 to $20 worth of administrative effort to purchase a $1 item or to sell some postage stamps to an employee. Unfortunately, the justification for an alternative procedure is not always this clear.

A slightly different kind of question of this type is whether or not a standard procedure should be enforced under extreme circumstances. For example, a procedure for reporting the transfer of capital equipment from one building to another, or from the responsibility of one department to another, was designed for the normal case of occasional trans-

* For specific information concerning classifications and symbols, and the design of coding plans, see Cecil Gillespie, *Accounting Systems: Procedures and Methods* (New York: Prentice-Hall, Inc., 1951), Chapter 6.

fers of one or two items. Then, for moving a large amount of equipment from one plant to another, provision was made for transferring up to 25 small items packed in the same box using one "transfer tag" supplemented by a packing list. Thus the basic procedure for transfer notification remained in force for these mass moves, but a simplification of the paperwork was permitted.

Sometimes an alternative procedure may cause more trouble than it is worth. For example, consider the following situation. The finished goods inventory is under the physical control of the shipping department, but the authority for releasing product units is assigned to the sales department. Frequently, finished units must be withdrawn from stock for modification, retesting, or for temporary use for special purposes. The standard procedures for releasing and returning finished-stock units originally were consistent with the procedures for other inter-departmental transfers of product. Thus, all additions (and returns) to stock were reported by "transfer list," and all releases from stock were authorized and effected either by shipping ticket or by transfer list. Subsequently, a simplified informal procedure was instigated for "borrowing" items from stock. In this case, it soon became apparent that the disadvantages of the alternative procedure outweighed the advantage of slightly less paperwork. It was not clear which cases should be treated as "borrowing," and in several other ways the existence of two procedures caused confusion, errors, and difficulty in reconciling records.

In designing the system in Example I (Art. 1.4), consideration was given to the idea of providing a special procedure for issuing a standard tool permanently to a machine on which it would be used for many different jobs. Under this procedure, a tool would be issued against a requisition signed by a foreman. No tool tag would be required, and no record would be kept of the location of that copy of the tool. The requisition slip would be used by the crib attendant to authorize fabrication of another copy of the tool to replenish the crib supply The question here was whether or not continuous control should be maintained for all copies of all standard tools in existence or whether exceptions should be made in certain cases. Although the suggestion had considerable merit, it was finally dropped in favor of the single uniform procedure for issuing standard tools.

6.3.2 Multiple-item or single-item procedure? In many procedures, one of the first decisions to be made is what shall be the normal unit of system work—a single item, a group of items of one class, or any assortment of items requiring similar action at the same time? For example, in designing a parts and materials procurement system, there is the possibility of restricting each purchase order to a single item. For non-catalog items (subcontracted parts and subassemblies), copies of single-item purchase orders may then be sorted, processed, and filed by part number in all departments affected (such as planning, production control, and quality control, as well as purchasing). Whereas multiple-item purchase orders could save some time and paper in purchasing, they might have to be broken down and transcribed onto individual part-number records in several other departments, and the over-all cost would be excessive. On the other hand, purchase orders for raw materials, commercial parts, and supplies might be handled most efficiently by combining as many similar items as possible on each purchase order.

In general, multiple-item procedures are desirable and efficient if they are properly designed. Some of the things which should be given careful consideration are as follows:

1. If any single item in a list cannot be treated in the normal manner, either the processing of the remaining items is delayed or supplementary paperwork is required. An example of this was cited in Art. 2.2.

2. A multiple-item document must remain in active status in the various files and records, and be included in all

tabulations, and the like, until the last action is completed on the last item.

3. If the items need to be treated individually or sorted into another classification, at one or more subsequent points, the advantages of the original grouping may be more than offset by the cost of transcribing or using poorly classified data for these other purposes.

In many cases, single-item records may cost a little more to originate than a list, but will pay off handsomely in the long run. Not only can the set of individual records be sorted into any classification, and re-sorted into different classifications for different purposes, but also items can be added and deleted readily. For example, a log sheet record of jobs in process can become extremely unwieldy if there is considerable variation in time-in-process. Currently active jobs are then scattered among many pages of completed jobs. Also, the classification of items in such a list is ordinarily restricted to chronological or numerical sequence. For many purposes this is quite appropriate and perfectly satisfactory, but frequently it is not.

Work-in-process control systems are sometimes based on unrealistic assumptions about the processing of multiple-item paperwork. The usual results are excessive cost and paperwork delay. For example, a dispatching and control scheme for a complex mechanical product was set up on a lot-by-lot basis. This proved to be unsatisfactory because a large percentage of the individual items were reworked or given special processing one or more times. Therefore, "split lots" were the rule rather than the exception, and for lots of more than two items excessive supplementary paperwork was required. Clearly, multiple-item procedures were not appropriate in this case.

6.4 DESIGN FOR THE MAIN VOLUME OF WORK

Many systems have failed to achieve maximum economy and effectiveness because their design was too heavily influenced by branchline procedures, special cases, or extreme variations which occur infrequently.

Economy in secondary procedures should not be had at the expense of the mainline procedures. For example, in planning quality control procedures which deal with the results of inspection, it is helpful to keep in mind that for the large bulk of the cases the result is acceptance rather than rejection. Thus, it is quite appropriate for the basic paperwork to be designed for the efficient treatment of inspections which fail to turn up any defects, and to provide supplementary procedures and forms to handle the important but less frequent cases of rejection. Here, the decisions and actions required in the minority case are considerably more complicated and require recording, transmitting, and using information which is not otherwise necessary. Unfortunately, forms and procedures are often designed which require unnecessary work in most of the cases in order to simplify treatment of the exceptions. Such examples are not limited to the field of quality control.

The same problem comes up in a slightly different form in systems covering a wide range of items or cases which differ in various ways. Procedures relating to capital equipment (see Art. 3.5.3) are an example of this. Any procedures which are to cover the whole range of capital equipment must be sufficiently adaptable to accommodate unusual and extreme items but should be designed primarily for efficient processing of the main bulk of items which are "typical" with respect to method of acquisition, value, physical characteristics, and other parameters. Special cross-classifications which represent a small fraction of the total, such as government-owned or rented equipment, for example, should not unduly influence the basic procedures. It may be better to provide supplementary procedures and forms for such special classes of items. If the product line of the company is varied, procedures for functions such as production control can become exceptionally unwieldy and expensive if they are de-

signed primarily for the more difficult cases. Here again the best approach may be to establish a basic pattern for the system and then elaborate the procedures for extreme items as necessary.

There are usually a number of quantitative variables which affect the system design. For example, the number of jobs recorded on daily time cards, the relative magnitude of factory orders, or the distribution of system workload by hours, days, or months. In general, it is better to make special provision for the extreme cases than to over-simplify or over-complicate the procedures and forms for the run of the work.

6.5 ADMINISTRATIVE CONTROL

There are two general ways of controlling the results of a delegated activity. The most obvious is to require the prior review and approval of the responsible executive for each occurrence of certain specified events. The other approach is to allow decisions to be made and actions to be taken in accordance with predetermined plans and to provide for reviewing and checking the results. The essential difference is the degree to which authority is delegated. Both techniques are useful, effective, and efficient under appropriate circumstances. Prior approval tends to be more suitable when the event being controlled has an important monetary significance, and the frequency of occurrence is small. Subsequent review is likely to be more desirable when the repetition rate is high and the possible consequences of each case are less serious.

6.5.1 Use prior approval sparingly. There is a strong tendency to require prior approval of repetitive actions where the delay and the necessary executive time are not warranted. For example, plant manager review of all purchase requisitions, regardless of the nature of the item or the amount of money involved, is a relatively expensive and unsatisfactory method of controlling expenditures. Nor is it likely to be worth while for a company officer to review all outgoing correspondence in an effort to protect public relations and avoid unintended commitments. Such procedures reflect inability or reluctance to delegate authority properly, either because of lack of confidence in subordinates or because subordinates are unwilling, for various reasons, to assume full responsibility.

Prior approval procedures are often instigated by persons other than the approver or his subordinates. Not uncommonly, the motive is self-protection rather than benefit to the company. The case cited in Art. 2.3 is an example of this.

A common mistake is to assume that checking each case beforehand will accomplish the desired control. For example, executive approval of each new hire, promotion, raise, and transfer does not provide assurance that the total work force will remain commensurate with production, sales, and income. Here, individual prior approval may be well worth while, but it should be supplemented with a less detailed comparison of over-all results against plans. Or, all such changes proposed each month might be submitted for approval at one time together with an appropriate control report, so that both the immediate direct effects and the long-run total effects can be considered simultaneously.

6.5.2 Control by subsequent review. Control of delegated activities by periodic review of results is effected by comparing actual performance with that which was intended and taking action with respect to significant differences.* Necessarily, predetermined plans must establish goals and standards of performance as well as policy, procedure, and organization. If an appraisal of results is to be meaningful, it is essential that both the reviewer and the reviewed have a clear and common understanding of what is expected.

Most schemes for subsequent-review control invoke the principle of manage-

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* Newman, *Administrative Action*, Chapter 23.

ment by exception. Thus, the reviewer concentrates attention on the important deviations, both good and bad. Obviously, when undesirable events occur, appropriate corrective action must be taken to minimize the consequences and to reduce the probability of their recurring. Otherwise, the entire process is worthless ritual.

6.5.3 Administrative control mechanisms. The procedures, methods, and forms for implementing an administrative control should be designed to fit the situation. In most cases, the possibilities are innumerable; there is seldom an obvious answer. One approach is to invent a suitable scheme, working from basic ideas and applying available knowledge of system techniques and devices. Another is to adopt a plan which has been successful in a similar case and modify it to suit the special conditions of the immediate problem.

The mechanisms by which control systems accomplish managerial purposes are similar in many respects to the methods of controlling errors, omissions, and delays within a system, which are discussed in Art. 7. More specific information concerning system devices and methods is presented in Art. 12.

6.6 AN APPROACH TO SYSTEM DESIGN DECISIONS

Many decisions must be made in planning and designing a system. Each such decision involves a choice between two or more alternatives. The objective in each case should be to select the alternative which will be most economical for the company as a whole in the long run.

The differences between system design alternatives are likely to be numerous. In other words, many different kinds of future receipts and disbursements of the company may be affected by the decision. In addition, there are likely to be secondary effects on the costs and benefits of related systems. Of course, all system design decisions should be made from the viewpoint of what is best for the company as a whole rather than from the viewpoint of what is best for a single person, department, or system Also, because systems and procedures tend to be self-perpetuating, it is important to consider the long-run as well as the immediate future. If a design decision must be based mainly on short-run considerations, it should be so qualified, and provision should be made for reviewing the system when conditions change.

One or more of the benefits of a system may lie in minimizing the probability of an undesirable event. A design decision may affect such a benefit in either or both of two ways. It may change the probability that the event will occur (in any one year, for example), and/or it may affect the value of the loss which will result if the event does occur. It is necessary to judge both factors for each alternative in order to evaluate the net difference between the alternatives.

In general, all system design decisions should be approached from the economy study viewpoint,* even though it may be necessary to base many choices on relatively rough informal estimates.

7. BUILDING ASSURANCE INTO THE SYSTEM

One of the main objectives of system design is to provide adequate assurance that poor decisions, errors, omissions, delays, and other system failures will not have serious consequences. To achieve this, the following things can be done.

1. Design the system so as to:

A. Minimize opportunities for failures—i.e., minimize their probability of occurrence.

B. Provide methods and procedures for detecting and correcting all the important kinds of failures which can be anticipated.

* See Section 3. Also Grant, *Principles of Engineering Economy*, 3rd ed., Chapters 1, 2, and 11.

2. Design critical procedures so as to minimize the effects of inherent human fallibility. (See Art. 8.)

7.1 SOME WAYS TO ELIMINATE SOURCES OF SYSTEM FAILURES

1. *Avoid transcribing information.* Each time an item of information is transcribed from one document to another, or from one medium to another, there is an opportunity for error. These often can be eliminated by providing duplicate copies of original records for all necessary uses.

2. *Avoid the use of biased information.* For example, if the only alternative to charging time to direct labor jobs is to report it under the description "idle time," a considerable amount of indirect labor will be reported as direct labor. In other cases, information may be biased unintentionally. For example, process yield figures used for planning parts procurement and release would be pessimistically biased if based on rejections reported rather than actual scrap.

3. *Use first-hand information.* It is frequently tempting to use available information for purposes for which it is inappropriate and was never intended. The misuse of accounting figures in making administrative decisions is probably the most typical mistake of this kind. Secondhand information may be badly biased, out of date, not sufficiently accurate, or it may be something other than what it is assumed to be. It is better to use source information wherever possible unless it is unduly expensive.

4. *Avoid accumulation of residual errors.* For example, a running balance of purchase order commitments was brought up to date each week by adding the total amount of new orders and subtracting the amount paid against open orders. Of course, all undetected errors were carried forward indefinitely in the running balance. A similar difficulty is encountered with many perpetual inventory records.

5. *Avoid biased decisions.* There are many factors, other than personal and social, which may undesirably influence repetitive decisions. Examples are pressure of time, misdirected budgetary incentives, extraneous information, incorrect methods of computation, and illogical methods of analysis. Such factors can often be eliminated, or their effects minimized, by proper design of the system.

6. *Don't oversimplify complex decision-making steps.* When a certain type of decision must be made many times, there is a tendency to resort to habit, rule of thumb, or a mechanical method employing a formula, chart, or graph. Common examples are decisions about purchase quantities, lot sizes, budgets, schedules, estimates, and price quotations. Although it is important to minimize the cost of making such decisions, it is more important that the decisions be reasonably good.

7.2 SYSTEM FAILURES SHOULD BE EXPECTED

Regardless of how well a system is designed, poor decisions, errors, and omissions are virtually inevitable. There is always a considerable difference between theoretical and actual results. In fact, it is not reasonable to expect otherwise—if no failures occur, the system is undoubtedly too elaborate and expensive.

Beginning with the premise that failures will occur, the first problem is to predict, from local experience and analysis, what kinds they will be, and at what point each will originate. The next problem is to establish mechanisms to disclose and counteract these expected failures and to reduce the chances of their recurring. Of course, the methods and procedures for doing this must cost less than they save.

7.3 AUTOMATIC CORRECTION OF SYSTEM FAILURES

One of the best defenses against an expected type of failure is to design the system so that the effects of

such failures will automatically be eliminated in the normal course of the system operation. This can be done in certain kinds of situations by having new plans supersede previous plans (or the latest information supersede previous information). The point of view applied here is that the information used in making present decisions about courses of action and plans should be the most current available data concerning present status and future events. Such decisions may be guided by, but should not be based solely upon, historical data which may be out-of-date or contain previous errors or information which is not pertinent. Following are some examples of the application of these ideas to assurance problems of system design.

An alternative to the method of determining the amount of money committed against open purchase orders described in Art. 7.1 would be to run a tabulation of the actual open orders. For the same amount of clerical work, a reliable figure could be derived quarterly, or perhaps monthly, directly from this current and reliable source of information.

The idea of superseding previous plans with new plans which start immediately is illustrated in the order-filling system of a large mail-order house. Merchandise picking and assembly by orders is planned and controlled by a block scheduling technique. Work is scheduled in 20-minute blocks, and that which is not accomplished in the expired period is automatically incorporated into the plans of a subsequent period.

Materials control schemes wherein new orders are initiated to replenish stock according to the results indicated by cumulative perpetual inventory records are always vulnerable to errors and delays in transmitting and recording information about withdrawals and additions to stock. An alternative (or supplementary) technique for eliminating the effects of such errors is to determine (or verify) the actual quantity on hand directly from the point of storage. For example, if notice is received from the stores clerk that a minimum supply package was opened at a certain time, this is a positive piece of information which is independent of that derived from the receiving reports and stores requisitions.

7.4 SYSTEMATIC DISCLOSURE OF SYSTEM FAILURES

Where automatic correction is not feasible, the alternative is to provide suitably reliable means of disclosing the system failures and initiating appropriate corrective action.

7.4.1 Detecting omission of a task or procedure. In Example II (Art. 1.4), assurance against failure to debit a vendor for returned parts is provided by serial number control of the Rejection-notice — Shipping-ticket — Debit-memo form. For each debit memo received in accounts payable, the date of receipt is recorded opposite that serial number on a preprinted number list. If a serial number is skipped and remains outstanding more than ten days, follow-up inquiry is made by telephone.

Another technique is to require matching of documents, such as invoices with receiving reports, inspection reports with interdepartmental transfers, and requisitions with purchase orders. These matching operations are not only useful in detecting omissions, but also provide an opportunity for various information checks.

7.4.2 Failure-detecting mechanisms should be as automatic as possible. Sometimes a system can be designed so that the detection of an important type of failure is inherent in the normal operation of the system. In Example I (Art. 1.4), a chronic shortage of copies of any one tool is virtually impossible because each time a tool is requested and not available in the crib, action is automatically initiated through the foreman, not only to solve the immediate problem, but also to correct the basic cause of difficulty. The type of action the foreman should take is indicated by the tags and checks hanging on the section of

rack for that tool. This general idea of automatic disclosure of errors, omissions, delays, and deviations is the basic principle on which numerous devices for scheduling, follow-up, and control are designed. (See Art. 12.)

7.5 THE BALANCE-CHECKING TECHNIQUE OF CONTROL AND ERROR DETECTION

Wherever control information can be reduced to quantitative form, there is the possibility that certain kinds of system failures can be detected by a routine or periodic balance-check. The basis of this method is an equation; the check is obtained by determining whether or not the equation is in balance at a particular time. If a difference is found, corrective action can be taken to reconcile it and eliminate its cause.

The most common example of the use of the balancing method for error detection is the double-entry scheme of recording transactions in accounting ledgers, wherein two equations are maintained in balance simultaneously (assets − liabilities = ownership, and total debits = total credits). A large variety of mistakes, errors, and omissions can be detected by checking the balance of these two equations for a general ledger. This principle of equation balancing is very widely applicable in the design of administrative controls, as well as in methods of detecting clerical errors. Applications of two of the most useful types of equations are described below.

7.5.1 The fixed-sum equation. Probably the most common type equation used in systems work is:

$$(\text{Sum of the parts}) = (\text{Total})$$

where the total is either a fixed quantity or can readily be determined by physical count or observation. Examples are as follows:

In Example I, provision is made for detecting the loss of a tool, so that it can be relocated or replaced, by periodically checking the balance of the following equation for each tool:

$$(\text{Copies in rack}) + (\text{Copies at grinder}) + (\text{Copies signed out}) = (\text{Total quantity})$$

Here the "total" is the stock quantity, which is recorded on the bin label. Notice that this check would not be available without the "At Grinder" checks. (See Fig. 6.1 and 6.8). In general, if any term or factor of a control equation is missing, or its value is assumed or derived from the equation itself, a satisfactory check is not possible.

Another example of a balance check is illustrated in Fig. 6.11. The total hours for the time report period (33.0) is the sum of the daily totals. The sum of the hours distributed to jobs and accounts must add back to this figure. Thus there is a check on the arithmetical accuracy of each time card, which also provides assurance that all the employees' time is accounted for each week. Note that this does not protect against improper distribution of the total time.

7.5.2 The input-output equation. The second most useful type of balancing equation is:

$$(\text{Starting balance}) + (\text{Quantities in}) - (\text{Quantities out}) = (\text{Ending balance})$$

This equation is the basis of any quantitative control record of materials or things of the same classification or status. The key idea here is that the balance at a particular moment is the difference between what has gone in and what has come out. Thus, if all additions and withdrawals are recorded accurately and without undue delay, the control record balance should equal the actual balance. The primary check is obtained by comparing the derived balance against the actual, as determined by observation or other direct means. A secondary order of checks on the accuracy of the system tasks can be obtained by simultaneous application of the balancing equation using group totals in place of individual transaction quantities. If the results do not agree, error is sought out and corrected.

The most obvious application of this input-output equation is in the control

WEEKLY TIME CARD A-46

NAME	A. B. Seedeeph	BADGE NO.	0919
PERIOD ENDING	9-30-54	CLASS CODE	TM
APPROVED	V.d.P.	SHIFT NO.	1
CHECKED	in	DEPT. NO.	22

	SUN	MON	TUE	WED	THR	FRI	SAT	SUMMARY	
IN		8 00	8 00	8 00	8 00			SHIFT PREM.	—
OUT		4 30	4 30	4 30	5 30			O.T. PREM.	0.5
TOT.		8	8	8	9			TOTAL HOURS THIS PERIOD	33.0

DESCRIPTION	T-5307						J.O. OR ACCT NO.	90-1215	
	SUN	MON	TUE	WED	THR	FRI	SAT	COST CENTER	HOURS
HRS.		8.0	4.7					12	12.7

DESCRIPTION	T-5307						J.O. OR ACCT NO.	90-1215	
	SUN	MON	TUE	WED	THR	FRI	SAT	COST CENTER	HOURS
HRS.			1.8	5.5				14	7.3

DESCRIPTION	Sick						J.O. OR ACCT NO.	22-102	
	SUN	MON	TUE	WED	THR	FRI	SAT	COST CENTER	HOURS
HRS.			1.5					—	1.5

DESCRIPTION	T-6113						J.O. OR ACCT NO.	90-1673	
	SUN	MON	TUE	WED	THR	FRI	SAT	COST CENTER	HOURS
HRS.				2.5	9.0			12	11.5

DESCRIPTION							J.O. OR ACCT NO.		
	SUN	MON	TUE	WED	THR	FRI	SAT	COST CENTER	HOURS
HRS.									

DESCRIPTION							J.O. OR ACCT NO.		
	SUN	MON	TUE	WED	THR	FRI	SAT	COST CENTER	HOURS
HRS.									

DESCRIPTION							J.O. OR ACCT NO.		
	SUN	MON	TUE	WED	THR	FRI	SAT	COST CENTER	HOURS
HRS.									

FIG. 6.11 EXAMPLE OF A BALANCE CHECK INCORPORATED INTO THE DESIGN OF A FORM.

of inventories, such as finished goods, parts, materials, supplies, tools, and equipment. Another general area of use is in the control of work-in-process and other inventories which are not only highly active, but also are often classified according to status as well as physical location.

For example, consider a six-stage process through which the basic part of a product passes while other parts and materials are joined with it to make a finished unit. Clearly, the above equation applies to this process as a whole. The parts and materials fed in, less the scrap and finished units turned out, should be the balance in process. (Technical difficulties may be encountered with respect to units recirculated within the process, units borrowed and returned, and units held in doubtful status, but these things can be provided for.) To go further, this control equation can be applied to each of the six stages of the process in sequential fashion, providing the basis for various internal controls as well as accuracy checks.

Application of this input-output equation to a single operation is sometimes complicated by the difficulty of measuring one of the minor quantities. For example, in many processing operations, the practical measure of quantity is weight rather than count. An extraneous factor affecting weight, such as oil, oxygen, or other material "picked up," or volatile material "lost," throws an unknown into the equation. Usually, the appropriate solution is to solve for this unknown for each lot or each period of time, and to compare this derived quantity with an expectation based on past experience. Significant deviations can then be investigated.

In the ordinary applications of this equation, timing may be a very real problem. All transfers which actually occur prior to the time the balance is verified (by physical count, for example) should be taken into account in computing the closing balance on the control record, and subsequent transfers should not. The answer is to establish a definite cut-off date and time and make sure that the actual effective time of each transfer is recorded.

Another problem, often more important, is providing assurance that the information flowing into the control record is complete as well as accurate, and is received in time to be of value. The control mechanism itself provides a way to check this, but if the information is typically afflicted with errors, omissions, and delays, maintenance of the control record may become ritual instead of useful work. The reconciliation of differences may degenerate to merely adjusting the record, which is then merely a source of information of doubtful reliability.

7.6 OTHER METHODS OF CHECKING AND CONTROLLING SYSTEM RESULTS

The methods discussed in Arts. 7.4 and 7.5 frequently can be so integrated with the essential tasks of the system as to require very little additional work. By contrast, the methods described below ordinarily require supplementary procedures.

7.6.1 Review of results. A general method of protecting against system failures is to review key documents at appropriate points in the system process. Apparent mistakes, unusual deviations, impossible or improbable answers, and incorrect decisions often can be spotted by this method. Such review should ordinarily be carried out by someone other than those who did the original work, usually a supervisor. Unfortunately, many such review operations are expensive in time and effort and yield very little benefit. So-called "rubber stamp" approvals fall in this category. On the other hand, reviewing can be very profitable if it is well planned, sufficiently selective, and propperly done.

7.6.2 Work repetition. Sometimes, the accuracy and completeness with which a clerical task is performed cannot be checked satisfactorily except by repeating the work. A straightforward example is the use of the verifying-punch operation to check the coding and preparation of information for machine processing. In this case, the entire task is repeated in a very similar way by a different operator. Another variation of the full-repetition method of checking is to have the same task performed independently by different people, and preferably by

different methods, and then to compare the results. More commonly, repetition checking is done only on selected parts of key tasks, and is accomplished by considerably simpler methods than those employed in the original task. In general, checking by full or partial repetition is most effective if the checking operation is as independent as possible with respect to method, operator, and sources of information.

7.6.3 Sampling methods. Frequently, a much better answer to problems of detecting and eliminating or controlling system failures is to check properly selected samples of the system work and apply appropriate statistical methods. Better results and/or less cost can often be achieved by this approach. In general, statistical techniques can be employed effectively to isolate and diagnose causes of trouble which can be eliminated, and to control within tolerable limits those kinds of trouble which are inherent in the system. Of particular value for this are the techniques of statistical quality control.* Although originally developed for problems of manufactured quality, these methods are suitable and powerful tools which are rapidly spreading in application into areas such as this.

7.7 MINIMIZING SYSTEM TIME-IN-PROCESS

One objective of system design is to minimize the time required to process documents, obtain decisions, produce reports, and accomplish other system functions. This is particularly important in systems dealing with customers and vendors and in systems for internal control. Following are some of the things which can be done in designing a system to help minimize time lag.

1. *Keep the system process simple.* Omit borderline operations, approvals, reviews, transmittals, and storages of the system documents. Combine related steps where possible. Involve as few people as possible.

2. *Plan simultaneous procedures.* If possible, split long sequences into two or more parts for concurrent action.

3. *Design procedures properly.* (See Art. 8.)

4. *Fix responsibility for the time of each step.* Establish deadlines for specific people and departments. Provide for recording the time at which key steps are completed—for example, require recipients of routed documents to sign off with both initials and date.

5. *Provide for follow-up.* Establish control points so that progress can be determined and delayed items located. Utilize a suitable reminder mechanism for initiating follow-up. Place follow-up responsibility with the person or group most concerned.

One danger of these anti-delay techniques is that if they are not properly applied they can be unduly expensive and may even increase the system time.

8. SOME PRINCIPLES OF PROCEDURE DESIGN

A fundamental problem in the design of an administrative system is to facilitate correct and proper action of the individuals involved in its operation and to promote satisfactory timing of these actions in accordance with predetermined plans. The solution to this problem is to devise procedures which take maximum advantage of the unique abilities of human beings but are realistic with respect to their inherent fallibilities. Weak procedures amplify human weaknesses and foster mistakes, poor decisions, omissions, and delays. Well-designed procedures help the employees avoid such failures.

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* See Eugene L. Grant, *Statistical Quality Control* (New York: McGraw-Hill Book Company, Inc., 1946). Also, Robert K. Mueller, *Effective Management Through Probability Controls* (A Modern Industry book) (New York: Funk & Wagnalls Co., 1950). Refer also to Sections 13 and 14.

8.1 PROCEDURES ARE FOR PEOPLE

This simple statement adds little to the meaning of the word *procedures*, but it is the key to adequate understanding of certain problems of their design. Procedures are plans for expending human effort and time to get things done. They are prescribed courses of action to be interpreted and followed by people. They should be designed to suit the requirements and peculiarities of human beings.

There is a tendency to assume machine-like qualities that people rarely possess and to ignore human qualities that commonly do exist. Machines think only in predetermined ways. They usually do what they are designed and instructed to do—promptly and faithfully, and in many cases continuously, without becoming tired or distracted or failing to remember information or method. Machines and devices thrive on repetitive standard chores; they are not inventive or creative. They tend to be accurate and reliable, and to possess exact memories. They lack emotions, and are capable of only preplanned discretion and judgment. In general, human beings are considerably different, and this should be recognized in designing procedures.

Procedures based on unrealistic assumptions about the expected performance of the people in the system are undesirable for two reasons. Directly, they cause mistakes, delays, and other system failures. Indirectly, they cause trouble because the individuals responsible for carrying them out are blamed for many failures which are inherent in the system.

8.2 A SYSTEM IS NO STRONGER THAN ITS WEAKEST LINK

The operation of a system depends upon a series of actions, each touching off and providing information for the next. An error or mistake at one point is usually relayed down the line. An omission or delay at any point stops the flow.

For the purposes of this article, at least, it is desirable to attach a somewhat more definite and limiting meaning to the word *procedure*. In this concept, a procedure is a set of related actions to be performed in a continuous sequence without interruption by one person or a team of people working closely together.

A significant interruption in the system process is then the termination of one procedure and the starting point of another. At this point, the chain of actions is broken and progress must be re-initiated. In other words, interruptions create gaps between procedures. These gaps must be bridged for each item or case processed through the system. At each of these gaps, some mechanism should be built into the upstream procedure to initiate the start of the downstream procedure. If this is not practicable, then the downstream procedure must be self-starting.

It is equally important to provide assurance that each procedure will be carried through once it is initiated. A breakdown within any one procedure in the chain has the same effect as a break between procedures—progress is halted for that item or case.

8.3 PROCEDURE ANALYSIS OF EXAMPLE I

The basic cycle of Example I (Art. 1.4) can be viewed as consisting of the four procedures described below. (See Fig. 6.8, Art. 4.5.)

1. Machine Operator and Crib Attendant: Issuing a tool from crib to shop, and recording its change of location.

2. Machine Operator and Crib Attendant: Returning a tool from shop to crib, and recording its return and pending dispatch to tool grinding.

3. Tool Grinder: Picking up returned tools at crib for inspection and sharpening.

4. Tool Grinder and Crib Attendant: Returning sharpened tools to the crib and recording their return.

Each of these four procedures is a logical series of related actions occurring without significant interruption. Between these procedures there are gaps in time and continuity.

Successful achievement of the purposes and objectives of this system depend, in the long run, on tools being available in the crib when they are needed. If frequently they are not, tools will be withheld and sharpened in the shop, and other ways of circumventing the system will soon become common practice. Therefore, procedures 2, 3, and 4 must not fail very often.

8.4 PROCEDURES MUST BE SURE-STARTING

The first requirement for the performance of a procedure is that the need for action must be brought to the attention of the proper person at the proper time. This means at a time when the task can be performed and the person is able to do it. A reminder which acts at an inappropriate moment is of little help.

8.4.1 Initiating scheduled procedures. When a certain procedure must be performed at some future time, it is usually necessary to set up a reliable reminder to initiate the deferred action. If the procedure represents a major portion of someone's job, habit may prove to be sufficiently reliable. Otherwise a special action-initiating stimulus may be required. This is the common problem for which such devices as desk calendars, bulletin boards, and alarm clocks have been invented.

Periodic procedures can sometimes be scheduled so as to be prompted by a normal pattern of events. Thus, if a procedure is placed on a regular basis to be undertaken "first thing Monday morning" or "each day right after lunch," for example, a relatively certain sequence of events is used as a cue to aid the memory. This technique is employed in connection with procedures 3 and 4 of Example I, wherein the tool grinder makes a daily trip to the crib to return sharp tools and pick up dull ones.

If a procedure must be undertaken for each case at some future date which can be determined or estimated in advance, a reminder device such as a date file, schedule rack, or come-up file is usually essential. Follow-up procedures, such as are employed in purchasing systems, are an example.

A less reliable method is to provide a persistent reminder which will repeatedly advise the employee of the need for future action. Classical devices for this are the string-on-the-finger, the pin-up note, and the "do" basket or file. Unless the number of things pending at any one time is small, the periodic task of reviewing the docket becomes a burden. Also, if the person does not remember to use the reminder, it is of little value.

8.4.2 Initiating action "as soon as possible." By far the vast majority of procedures are to be performed upon notification or as soon as possible thereafter. A common difficulty encountered here is that action must be postponed on some fraction of the cases handled, and as a result some are forgotten and others are seriously delayed.

The primary method of re-initiating action on postponed cases is to use a signalling device which acts persistently until action is taken. As a simple example, in one company new standard procedure sheets are inserted into the manuals using the top two rings of the notebook and the bottom two holes in the sheet. Thus a four-inch "flag" proclaims the existence of a new procedure until it is read.

The persistent signal idea is widely evidenced in the use of written memoranda, reports, and notices in place of oral communication. For instance, in Example II (Art. 1.4), each rejected lot is brought to the attention of the chief inspector by delivering the inspection report to his desk. Thus there is reason-

able assurance that he will initiate action to obtain a decision and dispose of the defective material without undue delay. Meanwhile, the material is flagged with a copy of the report and placed in a conspicuously located "hold" area where it acts as a continuous reminder itself.

8.5 DESIGN PROCEDURES TO ASSURE COMPLETE PERFORMANCE

Awareness of an immediate need for action does not insure that the procedure will be undertaken or, once started, that it will be carried through to completion. Satisfactory performance depends, in the long run, on two additional conditions—(1) acceptance of the procedure by the people involved, and (2) the existence of adequate motivation.

8.5.1 Design for acceptance. People will be considerably more willing and conscientious about following a procedure:

1. If the purposes and importance of the procedure are clear.
2. If it is as simple as possible and relatively quick and easy to accomplish.
3. If it is reasonably clear and definite concerning what is to be done and how.
4. If the required actions follow, one from the other, in a logical and natural sequence.
5. If it can be started immediately when the need for action is known.
6. If it can be carried through all at once without interruption.

8.5.2 Establish adequate motivation. For a procedure to prove satisfactory, the responsible employee must have a personal interest in seeing that it is accomplished properly and on time.

The most desirable solution to this problem of motivation is to assign the procedure, if possibie, to a person who will derive some positive benefit or reward from its performance. Next best is to place the responsibility with someone whose major duties depend on satisfactory conduct of the procedure. If this is not practicable, then provision should be made for the application of adequate supervisory pressure.

If an employee is assigned a procedural duty by his immediate supervisor, obviously he is going to be concerned about its performance. But frequently this is not enough. The employee also must know that satisfactory performance on his part will be recognized, and that unsatisfactory performance is likely to come to the attention of his superiors. People tend to do what is expected of them and to drop what they find is apparently not expected. Therefore, unless failure to conform to standard practice is brought to the attention of the responsible person by his supervisor, the procedure will degenerate and become unreliable.

In Example I (see Art. 8.3), each machine operator has an adequate personal interest in obtaining the tools he needs, but he is not so directly concerned about returning them to the crib. Where motivation is weak and the procedure is important to the system, as in this case, provision should be made for detecting violations and initiating corrective action. In this tool supply system, if a machine operator needs a copy of a standard tool and none are available in the crib, the foreman checks up on copies which have been signed out. If one is found at a machine where it is not in use, the consequences of failing to return it are pointed out to the responsible operator. Thus the system provides the mechanism and the information necessary for enforcing this procedure and eliminating sources of trouble.

8.5.3 System cannot replace supervision. If it is well designed, an administrative system is a valuable aid to supervision as a source of reliable information and a means of determining where and when action should be taken. Thus, good systems give direction and purpose to supervision and make it more effective. But, although systems tend to simplify the work of supervision, they increase, rather than decrease, supervisory responsibility. In effect, strong

systems make weak supervisors weaker and strong supervisors stronger.

9. SYSTEM COST REDUCTION

The costs of any system can be reduced. This is true even of new systems, because the "one best way" is a theoretical goal which can only be approached, never achieved. The objective in system cost reduction should be to achieve a level of efficiency beyond which further cost reduction effort is not worth while.*

This article is concerned with the task of reducing and maintaining at a reasonable level the costs of system operation. The general approach is that "there is always a better way to do it." Therefore, the problem of cost reduction is resolved to locating attractive opportunities for improvement and conceiving alternative ways of doing the same thing with less cost.

9.1 EACH INCREMENT OF SYSTEM COST MUST BE JUSTIFIED

Each separable part of the system must justify its own increment of cost by extra savings (or income) somewhere else in the company. In even the most well-managed companies, it is easy to find examples of procedures which exist for personal, departmental, or unknown reasons and contribute little or nothing to the company as a whole. It is also not difficult to find entire systems which produce important benefits but cost more to operate than they save. Obviously, such procedures or systems should be eliminated entirely or replaced. The first problem is to recognize these cases and isolate them for further study.

Many major systems have, among their purposes, one or more functions which are necessary for the operation of the company. A common mistake is to assume that, because certain functions of a system are essential, all the parts of that system are justified. This is not necessarily true. For example, some kind of accounts payable system is necessary, but it does not follow that all invoices must be checked for price and extension or that all freight bills must be checked for rate classification. It is quite possible to pay such obligations without benefit of these audits. These are marginal procedures. They should at least pay for themselves in savings obtained by correcting the errors they uncover.

In other cases, an entire system or a major part of a system should be studied as a candidate for elimination. This is always a possibility unless that part of the system provides a service without which the company could not operate. Fairly complex segments of control systems may fall in this category.

In Example I (Art. 1.4), tool bits must be supplied to the machine shop, and they must be sharpened or replaced when dull or broken. But the system for making sure that these tools are provided with the least expense, are available when needed, and are properly sharpened is a fringe which must pay for itself by savings in the cost of production and the costs of tools. The incoming inspection system of Example II must produce savings in the cost of purchased parts and the costs that would result if unsatisfactory parts found their way into assemblies and finished units, which clearly exceed the costs of inspection and the related paperwork and handling of materials. And each separable part of this system, such as the non-conformance report procedure, should also be expected to contribute more in savings than in expense.

9.2 ACHIEVING COST REDUCTION

In most systems, the preponderant cost is labor (wages plus expenses which run in proportion to wages). Therefore, the primary source of cost reduction lies in eliminating unnecessary

* Efficiency is used here in the sense of a ratio of worth-while expenditures to total expenditures.

work and simplifying that which is necessary.

The general approach should be to start with the system process as a whole and consider first the possibility of eliminating major groups of procedures and operations and then specific procedures and tasks. The idea here is to avoid spending time and effort to improve an activity which should be eliminated. That work which cannot be eliminated can usually be simplified by combining, rearranging, dividing, and streamlining the necessary procedures and tasks and related documents.

Cost reduction is accomplished only by changing things. The first step is to recognize opportunities for change which are likely to be worth looking into. To do this, observation and analysis must be supplemented by comparing what is found with preconceived ideas about what is desirable and what is not. Thus, it is helpful to judge each part of the existing system against the rules and principles of good design* and also to compare it with examples of poor design. The first involves testing parts of the present system against standards of excellence; the second is a matter of seeking specific kinds of evidence of waste and inefficiency

9.3 SOME POSSIBILITIES FOR IMPROVEMENT

The following is a listing of some of the things commonly found in administrative systems which indicate definite possibilities for improvement. In most instances, the change required to achieve cost reduction is to eliminate or correct the deficiency cited. Where the appropriate action is not obvious, possibilities are pointed out.

9.3.1 Forms and reports.

1. *Shotgun distributions*. If five or more copies of a report are being distributed, the chances are that one or more of these copies is not read, or if read is not acted upon. In a large company, a report listing all purchase orders completed each month, consisting of three to six single-spaced typewritten pages, was being compiled in accounts payable and distributed to scheduling, purchasing, expediting, and quality control. It was being filed (permanently) in all five departments, and the only place it was used was for an improper purpose. In another case, a daily report useful at three points was being multilithed and distributed to 15 points. Unnecessary copies should be eliminated. Another possibility is to make one copy serve the purposes of two or more by routing it.

2. *Wastebasket copies*. If a large fraction of the reports of a certain type (receiving reports for example) are being thrown away at different locations, perhaps a split distribution can be arranged. Those reports which are not needed at one point may be the only ones needed at another point. Another possibility to consider when reports are being thrown away is that the recipient does not want them, but does not know how to turn them off.

3. *Double-typed reports*. If a report must be typed twice to get the desired number of copies, either there are too many copies or the wrong method of duplication is being used.

4. *Separate forms that might be combined*. Producing two or more related forms with one typing saves time, money, and mistakes. Some of the best possibilities for combination are requisition and purchase order, purchase order and receiving report, sales order (and acknowledgment) and factory order, shipping ticket and invoice, purchase requisition and inventory record (traveling requisition), and receiving report and inspection report. There are many other such combinations.

5. *Poorly designed forms*. Forms that are not well designed are usually associated with poorly planned procedures. If the title of a form is vague, misleading, or ambiguous, the purposes of the form may also be doubtful. If a form is a

* Arts. 1-8, 11-12; also see Section 5.

standard "catalog item" or is run off on the office duplicator, it should always be viewed with suspicion.

6. *Complex daily reports.* Detailed reports, particularly those produced frequently and in numerous copies, are likely to be poorly suited to their purposes and little used. They are candidates for simplification or elimination.

7. *Late reports.* Progress and status reports received more than one period later than the period they cover (day, week, or month) may also be worth less than they cost.

9.3.2 Files and records.

1. *"Reference" files.* Many files and records are maintained which are used very little if at all. Some of these can be eliminated on the basis of two simple questions: "What real purposes does it serve?" and "How often is it referred to and by whom?" For example, questioning a file clerk who spent several hours a day maintaining a certain file disclosed that the only people who had looked at the file in the previous six months were the system analyst and the file clerk herself. The purposes for which this file was planned had never materialized. Similarly, many files originate for no real purpose at all, merely because people tend to save things they receive. For example, an engineer who had a desk drawer full of old daily production and scrap reports was asked if he ever looked at one after it went in the drawer. After a moment's thought he removed the contents of the drawer to the wastebasket and said, "Thanks, I can make good use of that drawer."

2. *Obsolete records.* Even when records are known to be obsolete they are sometimes continued by a conscientious employee in spite of contrary instructions. In an extreme case, an employee was found to have maintained a useless record on his own time because "he just couldn't understand how the company could get along without it after all these years."

3. *Protective records.* Very commonly, records are maintained for purely personal or departmental reasons, producing no benefit whatsoever for the company as a whole. One reason is distrust of other people's records; a more common reason is self-protection. If the real purpose of a file or record is to provide ammunition for possible internal arguments, its cost is difficult to justify.

4. *Logs and registers.* Chronological-listing records frequently exist for defensive reasons. If such a record prevents system failures, or aids in their correction, the only question is whether it pays for itself. If employed as a follow-up device, a more effective method may be appropriate. If employed as a protective device (see 3 above), it should probably be eliminated. In general, the real benefits of a log or register should be thoroughly questioned.

5. *Cross-reference files.* Files and logs or registers, which are maintained as an aid in locating items filed in another order, represent improvement possibilities relating to the system information and methods of classification. For example, related documents with separate identification numbers, such as sales order and factory order, purchase order and receiving report, or shipping ticket and invoice, create problems of cross-reference which can be eliminated by using the same identification number for both forms. Or, the serial number of a document can be designed to describe as well as to identify the item or case. For example, a compound purchase order number can designate the vendor, or a production order number can indicate the type of product. Another possibility is to eliminate the cross-reference file if the same document is filed in the same manner in another department and the frequency of reference is small.

6. *Inactive records.* Inactive records should be transferred out of working files. This reduces the time required to locate or file active items and saves file space. Inactive items should be disposed of immediately or marked for disposal at a certain date. Most documents can be destroyed after one year. Some should be retained as long as three to five years. Very few should be stored permanently.

7. *Unfiled filing.* Persistent quantities

of material waiting to be sorted and filed is sometimes an indication that the material should be destroyed rather than filed.

8. *Duplicate files and records.* The most obvious type of record duplication is where the same form or report is filed in different departments, or for different purposes in the same department, in an equally suitable order. One or the other of such files is likely to be a protective record. For example, an inter-departmental material transfer may be filed by the sender, the receiver, accounting, and production control. The sender's and receiver's copies should probably be eliminated, since a record of these transactions is available in two other locations. Somewhat more difficult to recognize are duplications of information in different records and records of different types which have the same general purpose.

9.3.3 Some questionable kinds of work.

1. *Checking.* Some of the classic examples of system cost reduction involve discontinuing a checking operation which was found to be of little benefit. The most attractive possibilities are in connection with work-repetition checking. (See Art. 7.6.2.) In a large company, for example, an invoice-checking operation was eliminated with an annual savings of $10,000.* Two alternatives to eliminating 100 per cent checking are control sampling (see Art. 7.6.3) and restricted checking. The latter involves checking only those classes of the given document wherein errors of major importance can be expected.

2. *Approval and acknowledgment signatures.* Routine signing of initials or name to indicate approval or acknowledgment is often a useless ritual. In many cases a signature is insisted upon when its purpose is merely to shift responsibility and possible blame. Signatures which are "automatic" or "protective" should be eliminated.

3. *Frequent inventory-taking.* Taking physical inventory is expensive. If such things as tools, equipment, and work-in-process are being inventoried frequently by physical count, there is always the possibility that some type of perpetual control record system would be less costly. For an extreme example consider the practice in one company of stopping work fifteen minutes early at the end of each day to count and record the work in process at each station. Not only did the reports derived from this information cost ten or more times the amount they should, but also they were exceptionally inaccurate. After a dispatching and control system was installed, physical inventory was taken only four times a year, instead of 250 times.

4. *Transcribing.* Copying information from one document to another should be eliminated whenever possible. One possibility is to design multi-purpose forms. In Example II, handwriting a five-copy set produces all papers needed for returning rejected material to a vendor—rejection notice, shipping ticket, and debit-memo. Such combinations should be considered wherever two or more forms must carry a number of the same items of information. In other cases, transcribing can be eliminated by modifying an information transmittal form and providing another copy to replace a posted record. Or, a record form may be used to transmit information which is currently being copied from the record.

9.3.4 Misplaced tasks. In general, detailed routine work should not be performed by high-paid personnel, and specialists should be relieved of administrative duties, particularly those involving paperwork, whenever possible. For certain classes of personnel, some types of work they often perform should be eliminated or transferred. Following is a check-list of such work:

1. Executive and professional personnel—checking, approving, routine writing, routine follow-up, record posting, filing.

2. Administrative managers and su-

* As reported by Jack R. Crowley in a talk presented to the San Francisco chapter of the Systems and Procedures Association of America, March 28, 1952.

pervisors—detailed checking and routine clerical work, including record posting and filing.

3. Foremen — administrative paperwork, record keeping, detailed planning, routine follow-up.

4. Specialists (skilled tradesmen, technicians, production operators, etc.)—record keeping, routine report writing, and other paperwork.

Another general possibility for cost reduction is to centralize repetitive tasks requiring special equipment and skills: duplicating, punching, collating, filing, sorting, addressing, stenography, and other such tasks.

9.3.5 Work duplication and overlap. Precise duplication of work by different people or by different departments, except for checking purposes, is relatively rare. However, tasks which overlap and duplicate each other in *purpose* are very common. This type of duplication frequently exists between systems, between individuals, and between departments. The appearance of the same or similar information in different records and reports is an indication of such duplications. Cases of overlap and direct duplication often exist between systems for quality control and production control, materials control and purchasing, purchasing and disbursing, cost accounting and production control, and industrial engineering time control and cost accounting, for example. These duplications cannot always be eliminated, but frequently the amount of overlap can be reduced.

9.3.6 Complex procedures for simple cases. Standard procedures which are suitable for handling transactions of considerable monetary importance are often absurdly expensive for simple cases. For example, consider the case of the man who purchased a home appliance and subsequently wrote to the manufacturer requesting a copy of the service manual. He enclosed his personal check for 75 cents, the listed price for the booklet. In due time he received, in a window envelope, a shipping order (Form NC-1416) and an acknowledgment copy, indicating that his check had been received and that one "part A-89, manual, service" was being shipped by prepaid parcel post on order number S-35483. Shortly thereafter the pamphlet (8½" x 11" size) arrived in a 10" x 10" x 5" carton box, together with the packing slip copy of the shipping order and a quantity of shredded paper. Postage and insurance came to 55 cents. A week later, in a window envelope, copies 1 and 2 of invoice number 131214 (Form NG1180) arrived. Apparently the amount due was 75 cents, although under "terms" there was the notation "Check rec'd .75." Both copies of the invoice were rubber-stamped to the effect that the goods had been produced in compliance with the Fair Labor Standards Act of 1938. A month later another window envelope arrived, by air mail, containing Form NC-1121, titled "Statement." This document showed first a credit entry of 75 cents, and then a debit entry of 75 cents and a balance of .00. Clearly, it cost this company more than 75 cents even to handle the customer's remittance! Probably a better plan would be to mail such booklets directly from the sales office or the mail room free of charge upon request.

For major inter-departmental procedures, such as those for external transactions like buying and selling, the type of business handled should be analyzed to discover such cases. Simplified alternative procedures should be set up to handle simple cases, which sometimes account for a large proportion of the system work.

9.3.7 Some other things to look for.

1. *Lack of standardization.* Minor variations required for different classes of items or cases handled by the system often cause unnecessary work. For example, invoices to government agencies and prime contractors must carry a statement certifying compliance with certain federal statutes. One company dutifully typed on each invoice the particular paragraph spelled out in the customer's purchase order. Soon there were six different "standard" paragraphs and several "special" ones in use. Finally,

the company attorney drew up one master statement which was then preprinted on the invoices to eliminate this typing. Another example of reducing costs by standardization is to establish the wage rates of all employees at prescribed increments (multiples of 5¢ per hour for instance). This simplifies payroll preparation and cost distribution, and reduces errors.

2. *Too many numbers.* If more than three or four identification numbers appear on a document, or in a tabulation, a possibility for simplification is to eliminate one or more of them. There is a tendency to record all codes and numbers bearing on the subject of the document, some of which may not be necessary and might be omitted. A better idea is to make one number serve the purposes of two (see Art. 9.3.2, Item 5, concerning cross-reference files).

3. *Indicators of basic fault in the system design.* Opportunities for reducing cost and improving system effectiveness are usually indicated by one of the following symptoms:

A. Supervisors engaged largely in "putting out fires."

B. Paperwork bottlenecks; excessive time lag and delay.

C. Frequent waiting for work or alternate waiting and rushing.

D. Excessive overtime.

E. A high percentage of the work processed as "rush" or "special" cases.

10. PROCEDURES INSTALLATION AND CONTROL

10.1 INSTALLING NEW SYSTEMS AND PROCEDURES

The objective in installing a new system or procedure is to do it as quickly as possible, without disrupting the continuity of records and operations, with the minimum of expense, and with maximum assurance that the new procedures will be readily accepted and properly followed. To thus accomplish, a procedural change smoothly and efficiently requires planning and preparation. If this is done well, delays, confusion, and temporary expedients which later must be unlearned, can usually be avoided. The greater the extent of change, and the more people involved, the more difficult is the problem of installation and the more important is the need for careful planning.

10.1.1 Planning the installation. Planning a system installation involves anticipating everything that must be done and deciding how and when it will be accomplished.

There are two sides to any change in procedure. First, some of the present procedures, records, and items of information are going to be dropped or altered. Second, some new things are going to be started. A common mistake is to concentrate on implementing the new procedures and to give inadequate attention to the effects of disturbing present routines. It is important not to overlook resulting dislocations and delays and changes which may be necessary in related systems.

If a new system involves numerous changes affecting many people, the possibility of installing it in segments should be considered. For example, changing a payroll system from a manual to a tabulating machine operation may require considerable modification of the time reporting forms and procedures. This part of the system probably should be installed before the changes within the accounting department are put into effect. Or, in overhauling a complete production control system, the installation might be broken down by segments such as scheduling and order release, dispatching and follow-up, and the preparation and distribution of control reports. Piecemeal installation has the advantage of simplifying the job of planning, overseeing, and coordinating those changes undertaken at one time. The disadvantages are that it takes longer to get the entire system into operation, and it often creates additional temporary problems.

10.1.2 Techniques of transition. There is no one best way to accomplish a

concurrent set of changes in administrative procedure and method. Any one or combination of the following plans may be appropriated in a given case.

1. *Switch-over method.* This is the obvious way—switching completely from the old to the new at a predetermined time. The time is commonly chosen as the end of a reporting period but may be specified in terms of a future event, such as the start of a certain production run or the writing of purchase order No. 10,000, for example.

2. *The attrition method.* This plan involves dual operation of the old and new procedures such that all new cases started through the system are handled the new way, but those in process (or not requiring immediate attention) are handled the old way. For example, to install a new inventory control system, the change-over for each item might be made when it comes up for review or reorder. Thus, by attrition, the old system would gradually be replaced with the new system.

3. *The overlap method.* This scheme is to start the new system (or build it up gradually) in parallel operation with the old system until the old one can be abandoned all at once at a convenient time. This method is, of course, expensive and may involve a temporary expansion of the work force or considerable overtime during the period of dual operation. Its advantages lie in testing out the new system before the old one is dropped and in avoiding possible gaps and errors in essential information.

10.1.3 Preparing for the installation. Following are some of the things which must be done before the new procedures are to go into effect.

1. *Procure necessary forms and equipment.* Many procedures installations have gone awry because inadequate lead time was allowed for the procurement of new forms, supplies, devices, furniture, or machines.

2. *Accumulate initial data.* Information which will be needed in the new procedures but is not currently available, particularly that required for planning and comparison, must be obtained or estimated.

3. *Set up new files and records.* All new equipment should be readied for use. This may include labeling bins or folders, marking items with identification numbers, or transcribing old records onto new forms.

4. *Instruct the personnel.* New procedures must be taught. Usually, training should begin sometime before the procedures are installed. Written instructions are helpful but should not replace personal and group explanation. Preferably instruction should be done by the immediate supervisors with the aid of sample forms, diagrams, and written procedures prepared by the system designer. Instruction should cover the installation plans as well as the new procedures.

10.1.4 Directing the installation. A new set of procedures is not completely installed until it has settled down to smooth, normal operation. Meanwhile, the persons who planned the changes must monitor the new activities, provide guidance, correction, and coordination, and solve the little problems which are bound to come up. This effort should normally taper off rapidly and soon become a matter of consulting and advising. Responsibility for procedure enforcement must, of course, lie with the immediate supervisors from the start.

10.2 PROCEDURES CONTROL

In all but the smallest companies, positive steps should be taken to control procedures. Control, in this sense, encompasses surveillance over the instigation of new procedures and the changing of old ones and enforcement of those which exist. It implies promoting coordination between departments and systems and continuously evaluating both present and proposed procedures. The purpose is to stem the rising tide of additional paperwork and procedure and ultimately to widen the net difference between the benefits and costs of the company's administrative systems.

The following are some of the things which can be done to help control procedures. They are complementary, and to some extent interdependent. To be effective they must be used in combination.

1. *Forms control.* Nearly all systems depend on forms for gathering, transmitting, and recording information. The layout of these forms essentially determines which items of information are processed and used in the system. The number of copies of each form essentially limits the number of uses and points of retention of this information. The first line of defense against unnecessary, uneconomical, and conflicting procedures is to control the design and production of all forms used in the company. Without forms control, procedures control is seldom effective.

2. *Systematic publication of standing plans.* A system of manuals which provides all employees with up-to-date knowledge of existing procedures, policies, organizational relationships, and responsibility assignments is an aid to procedures control. Such manuals establish a record of what has been decided and approved. This encourages conformance, makes enforcement possible, and discourages poorly planned and uncoordinated changes. To serve these purposes, the manuals must be reasonably complete, well planned and indexed, and properly maintained. The material they contain must represent agreement and carry authority.

3. *Systematic follow-up and review.* All procedures should be reviewed periodically to make sure they are going according to plan and have not become significantly modified in undesirable ways. This is particularly important for relatively new procedures and for those operating in unsettled changing situations. In any case, a scheduled program of system studies should be carried on to insure review of each major procedure at appropriate intervals. Such a program will thus serve the purposes of procedure control as well as system improvement.

4. *Equipment and supplies control.* Requests for office equipment and new kinds of office supplies are often associated with departmental changes or additions to present procedures. Many poorly conceived changes and unnecessary new routines can be headed off if such requests are reviewed by the person responsible for procedures control. This may or may not be worth while, depending on the situation.

10.3 FORMS CONTROL*

Systematic control of forms consists of reviewing each form, new or old, each time a new supply is requested. Such review should cover:

1. Design of the form with respect to possibilities for improving its utility, reducing its cost, and improving the methods and procedures for its use.
2. Cost justification, considering the present and future need for the form, the benefits it produces, and the costs of procuring, using, storing, and disposing of it.
3. Order information, including design specifications, order quantity, estimated price if to be purchased, delivery date, packaging, and storage and distribution instructions.

The main purposes of forms control are as follows:

1. Procedures control (see Art. 10.2).
2. Clerical work simplification.
3. Minimum cost of forms procurement and inventory.
4. Providing impetus and information for system studies.
5. Providing adequate assurance against running out of necessary forms.

10.3.1 How to institute effective forms control. The following is a suggested plan of attack for developing a forms control system which will adequately serve the purposes outlined above.

* See Frank M. Knox, *Design and Control of Business Forms* (New York: McGraw-Hill Book Company, Inc., 1952), Chapters 1 and 2. Also, *Simplifying Procedures Through Forms Control,* Management Bulletin, Executive Office of the President, Bureau of the Budget, June 1948.

1. Establish policies and procedures which will:

A. Clearly define what a form is, and which forms are to be controlled.

B. Fix responsibility and authority for designing and ordering forms with a specific person.

C. Establish a rule that no new supply of forms may be purchased or duplicated on office equipment without prior approval of the forms designer.

2. Establish inventory control over the basic supply of all purchased forms.

3. Place office duplicating machines under adequate control and regulation with respect to the reproduction of forms.

4. Establish a suitable set of files and records and a forms classification and numbering plan.

10.3.2 What is a form? A form is something prepared in advance to receive predetermined items of written information. Forms are ordinarily printed or duplicated on paper or card stock but may be of any material. Some of the types of forms include tags, cards, slips, paper documents, duplication masters, and many gummed and self-adhesive labels. The essential characteristic of a form, for the purposes of forms control, is that specified items of information are to be written on it (by hand or otherwise) in predetermined spaces.

10.3.3 Which forms should be controlled? In general, the only satisfactory answer to this is to control *all* forms with respect to both design and use. The only appropriate exceptions to this rule are:

1. Work sheets and record forms made by typewriter, by hand, or by photocopy. These are inherently limited in quantity and therefore in usage. They are also very difficult to control.

2. General-purpose stationery items, such as inter-office memo sheets, letterhead, vellum drawing sheets, and mailing labels.

Forms produced by printing press, offset duplicator, stencil duplicator, or hectograph duplicator are the ones which can and should be controlled. Of these, purchased forms are the most important, because this class usually includes the ones which are expensive and are used in large quantities and which affect the major procedures. Examples of common types of purchased forms are multiple-copy sets, padded sets, preprinted duplicator and photocopy masters, report and record cards, tags, and slips.

Inevitably, many forms are produced within the company if an office duplicating machine is available. These forms usually outnumber the purchased forms and are no less important. They should also be under forms control. Most of them are poorly designed, inefficient, expensive to produce (although costs are hidden), and are physical evidence of poorly planned procedures. Many of them are unnecessary or not worth while. If purchased forms are placed under control and these "homemade" forms are not, the number and quantities of the latter are bound to increase. A forms control system which covers only purchased forms can realize only a fraction of the potential benefits.

10.3.4 Forms control records. To implement forms control, complete information concerning each form should be collected and kept up to date. The file for each form should contain:

1. Sample copies, preferably including one filled out with typical data.

2. Current information concerning the use of the form.

3. Complete specifications for printing or duplicating.

4. Rate of use, past order quantities and dates, costs, obsolescence possibilities, and other procurement data.

5. Notes concerning possible improvements and cross references to related and similar forms.

All such information may be kept in a single file, although the record of past orders, usage, and costs, is often posted on visible-margin cards. In more elaborate systems, copies of the forms may be filed concurrently in two or more of the following ways: by form number, by use or function, by originating department, and by type of form.

10.3.5 Inventory control. Procedures

Form Title *Inspection Report (Revised).* Form No. *QC-27a*

Ordered from *Standard Press* Date Ordered *Nov 12, 1954*

FORM REORDER NOTICE			Order was received and distributed as follows:	
DISTRIBUTE NEW SUPPLY TO:	Approx. Qty.	No. Pkgs.	Actual Qty.	No. Pkgs.
Inspection Dept, Plant II	500	2	500	2
Inspection Dept, Plant I	250	1	250	1
Supply Room, Plant II	1,000	4	1000	4
Supply Room, Plant I	none	–		
Storage at Plant I — Open Stock	2,750	11	2950	12
Storage at Plant I — Min. Qty. Pkg.	500	2	500	2
Total Quanity Ordered/Received	5,000	20	5200	21

Notes: *Supercedes QC-27—destroy old stock on hand* Date *12-22-54*

By *A. Mann*, Procedures Dept. Date *11-15-54* By *J Bird*

FASTEN WHITE COPY OF THIS SLIP TO MINIMUM QUANTITY PACKAGE. RETURN PINK COPY TO PROCEDURES DEPARTMENT WITH 5 COPIES OF FORM.

WHEN MINIMUM QUANTITY IS OPENED OR ISSUED, REMOVE THIS SLIP FROM PACKAGE, ENTER DATE AND NAME, AND SEND IT TO PROCEDURES DEPT.

Min. Qty. Pkg. opened:

Date ______

By ______

FIG. **6.12** A THREE-COPY FORM DESIGNED FOR A FORMS INVENTORY CONTROL SYSTEM USING THE MINIMUM QUANTITY PACKAGE TECHNIQUE.

for initiating reorder of forms should be simple but effective. It is important to provide very strong assurance against total depletion of the supply and to provide sufficient lead time for reviewing the procedures and the form before releasing a new order. This is particularly important for purchased forms.

Perpetual inventory record schemes are usually too expensive and sometimes not practicable for inventory control of forms. An alternative, which has been successful in many applications, is the minimum quantity package technique. For example, when an order for a new supply of a particular form is released, a "form reorder notice" (Fig. 6.12) can be made out, specifying what has been ordered and how the new supply should be distributed. When the order is received, the supply clerk can then distribute the new supply and package the specified minimum (reorder) quantity as instructed. The reorder notice is then fastened to the outside of the minimum quantity package, which is placed in protective storage. When the open stock is exhausted, the minimum quantity package is opened and the reorder notice is sent to the forms designer for action.

10.4 PLACING RESPONSIBILITY FOR SYSTEM IMPROVEMENT AND PROCEDURES CONTROL.

As a company grows and changes, its policies and procedures also grow and change, under the special influences of many different people. Individually, these people are concerned only with certain systems and parts of systems. And at any one time their interest is centered mainly on immediate problems, costs, and results. Thus, normally, the administrative systems of the company undergo a process of patching and building which lacks coherence and coordination. The usual result is a complex tangle of relatively expensive and ineffective systems. To counteract this process, there should be a systematic effort to evaluate, plan, and coordinate changes of procedure and continually to promote

the point of view of the company as a whole.

In a small company, system improvement and procedures control are responsibilities of the chief executive. In departmentalized plants and companies, these tasks must be delegated. Ideally, the responsible person or group should:

1. Be relatively independent of those departments which are directly involved in the operation of major systems (in order to be objective and properly to resist biased departmental viewpoints).

2. Be endowed with sufficient authority and be capable of generating enough respect and acceptance to be effective and to operate efficiently.

3. Be properly equipped for the task.

Because procedures improvement and control are linked closely with organization planning, it is desirable for these functions to be placed together. Procedures control should include forms control and the editing and release of standard practice information. The person or group having these duties should be expected to provide effective technical aid, coordination, and ideas toward system improvement.

Obviously, if one or more persons in a company are engaged full time in system improvement and control activities, their cost each year must (at the least) be recoverable in immediate and future savings resulting from their efforts during the year. Unfortunately, the benefits of such work are not easy to show, whereas the costs are quite obvious.

11. FORMS AND REPORTS DESIGN

Most forms and reports are not well designed. They are usually conceived and produced without sufficient thought being given to their purpose and use, without adequate consideration of costs and alternatives, and without a reasonable amount of planning of content, captions, layout, and physical specifications.*

11.1 PURPOSES OF FORMS

In general, the purposes of any form are:

1. To standardize the presentation of similar sets of information with respect to sequence, arrangement, and the manner in which it is written.

2. To save writing by pre-printing fixed information such as descriptive captions, instructions, standard answers, and identifications.

3. To provide assurance that all necessary information will be recorded, and in the proper way.

4. To provide an economical means of producing written information in multiple copy.

All forms serve the first three of these functions; many also serve the last.

The costs of a form should be justified by savings in the time of the writers and users of the information it carries, or by reducing trouble caused by incomplete, inaccurate, and improper information, or both. As an implement of an administrative system, even a poorly conceived form is usually far better than no form at all. However, most forms fall short of providing a full measure of the benefits potentially available.

11.2 OBJECTIVES OF FORMS DESIGN

Apparently few authors of forms realize the importance of good thorough planning and design. Time and effort spent in this way can yield remarkable dividends. The cost of the form, and the time required to obtain it often unduly influence its design. Typically, the costs of using a form are from 10 to 20 times greater than the

* See Knox, *Design and Control of Business Forms*, for excellent examples of poorly designed forms and how they can be improved.

costs of the form itself.* It is not at all unreasonable to spend $150 worth of time on the design of a form which will cost $400 per year and will require $6000 per year to make it out, handle it, check it, use it, file it, and ultimately dispose of it.

The primary objective in designing a form should be to reduce the costs of its use. Some of the ways in which this can be done are as follows:

1. *Eliminate the form if possible.* Before spending time to design or redesign it, conclusive evidence should be required that the form will save more than it costs and that its functions will be worth while.

2. *Combine the form with another which is similar or related by use.* This may reduce costs in a number of the ways listed below.

3. *Simplify or eliminate writing operations.* Replace rewriting with reproduction. Eliminate items of information that are not worth while. Preprint all static information. Use ballot boxes with preprinted, standard, alternative answers. Establish standard abbreviations, codes, and other writing simplifications.

4. *Simplify or eliminate using operations.* Readability, location, and arrangement of information affect the speed and accuracy with which variable data on the form can be checked, used, and transcribed.

5. *Reduce handling and storage costs.* Consider sorting, counting, filing and unfiling, enveloping, typing, posting, mailing, and other operations to be performed. Size, grade, and weight of stock and layout of the form may affect these tasks.

6. *Minimize the possibilities of error.* Mistakes necessitate checking operations and corrective actions, and those which are not detected reduce the benefits of the system. Poorly designed forms encourage mistakes; well designed forms prevent them.

The general criterion for decisions about the design of a form should be minimum total cost of producing it, carrying it in inventory, writing it, using information it carries, and handling and filing it. The costs of the form itself are usually only a small part of this total.

11.3 PLANNING A FORM

A form is a custom-made special-purpose tool. It should be made to fit the job. Therefore, to design a form properly it is necessary to know its purposes and how it will be used. In general, a new form is not created and put to work without starting new procedures and tasks. The proper sequence is: First, establish the procedures. Second, plan the clerical operations. Third, develop the form and the detailed work methods. Curiously, many people begin with the design of the form and then back into the planning of procedures and methods. This approach should be avoided.

11.3.1 Determine the use of the form. To design a form properly, a clear idea of its functions and usage is essential. From an analysis of the existing or proposed procedures, the following things should be determined:

1. The number of copies required and the uses of each copy.

2. The methods of writing, mailing, sorting, filing, and using the form.

3. The rate of use (quantity per month or year).

If an existing form is to be redesigned, it is always a good idea to review a good sample of previously filled-out copies. Possibilities for simplification are often indicated by:

1. Items of information which are often omitted.

2. Extra lines and columns which are never used.

3. Variable data which seldom changes, or which is always one of two or three standard alternatives

* These estimates are based on studies conducted by Ben S. Graham, Director of Methods Research, Standard Register Company. Similar estimates have been reported by other professional system analysts.

Possibilities for improving the effectiveness and utility of the form may be indicated by:

1. Items of information which the form did not call for, or for which no definite place was provided.

2. Corrections and explanatory notes of common occurrence.

3. Frequently crowded writing in certain spaces.

11.3.2 Decide the size of the form. In determining the size of a form, the following factors should be weighed:

1. *Limitations and requirements of equipment.* Consider the machines and devices to be used in writing, reproducing copies, sorting, filing, and other operations. For example, 8½ x 11 is a preferred size of paper for many duplication processes, and 3 x 5, 4 x 6, and 5 x 8 are standard sizes for card sorting and filing equipment.

2. *The approximate total area needed.* The area required will depend on the items of information to be recorded, the method of writing, and the amount of space required for captions, instructions, lines, and background space.

3. *Economy of paper and printing costs.* In certain duplicating and printing processes, non-standard sizes may be impractical or unduly expensive to produce. For example, tags and multiple-copy carbon sets must be a standard size to be printed at low cost on special purpose machines. A related factor is paper cost, which is affected by the amount of waste in cutting a given size out of an available basic stock size. This last factor is of minor consequence for small quantities, but it becomes important for large numbers of sheets.

4. *Mailing, handling, and other methods considerations.* Review the present methods for work simplification possibilities. For example, an 8½ x 7 form is easier to fold and insert in a No. 9 window envelope than an 8½ x 11 form. On the other hand, an 8½ x 11 form may be easier to handle and file with other papers than the short size or half size.

11.3.3 Decide the type of form. The number of copies and the rate of use are the two major considerations in deciding the type of form and method of producing it. The objective, of course, is minimum total cost of procurement, inventory, and use. Except where the type of form is essentially controlled by the system equipment, there are usually a number of alternatives for which the relative costs should be compared.

For single copy paper forms (8 to 24 pound paper), the alternatives reduce to different methods of producing the form. The common possibilities are hectograph, stencil and offset duplication, and offset and letter-press printing. In general, the duplicating processes are limited to small quantities, depending on the life of the master. However, with offset duplicating from photo-engraved metal plates, an indefinite number of copies can be produced. Except for appearance, registration, and other quality factors, the choice of process for single-copy forms depends primarily on quantity. In general, the printing processes involve higher preparation and set-up costs and lower unit production costs. A common mistake is to ignore the possibilities of offset or letter-press printing, in favor of periodically running off small quantities of the form on the office duplicator. This is false economy unless the form is purely temporary, or unless only a few hundred copies will be needed per year.

For multiple-copy paper forms, there are many possible alternatives, subalternatives, and combinations. Below are listed the most common types of multiple-copy forms, classified by method of producing the copies, with general comments about their relative areas of economic application:

1. *Carbon reproduction.* Original and carbon copies are produced immediately in the writing operation. Number of copies is limited. Erasure corrections must be made on all copies. Legibility diminishes with successive copies. Weight and grade of paper is restricted, depending on number of copies.

A. Loose or padded without carbon: Generally not economical if total number of *sheets* per year is greater than 7,000 or 8,000. Cost of handling (and provid-

ing) carbon paper is major limiting factor. For handwriting, two or three copies per set are satisfactory; four copies is recommended maximum. For typing, three or four copies are satisfactory; five or six copies are practicable. Padding is worth while if handwritten, and usually pays off for typing in four or more copies. See Fig. 6.12 for an example of a 3-copy padded form for handwriting which was printed by offset duplicator from a typewritten master and padded with cold glue.

B. Unit set with one-time carbon: Generally economical if total number of *sheets* per year exceeds 5,000 to 6,000. Printing and assembly involves relatively high fixed costs per order, low cost per sheet. For handwriting, two to four copies are satisfactory; six is recommended maximum. For typing, up to 8 or 10 copies is possible on ordinary machines; up to 16 or 18 with special equipment. Affords numerous subalternatives and special possibilities, such as continuous forms for writing machines, use of carbon-backed paper, omission of information on certain copies, and disassembly into sub-sets for different uses.

2. *Duplication methods.** All copies are produced by machine from a preprinted master on which the variable data have been written. Number of copies is essentially unlimited. All copies are equally legible. Weight and grade of paper is restricted depending on process. Reproduction involves extra handling and delay before copies are available. Erasure corrections are made once, on master. If master can be re-used for producing a related report, or with added or altered data, considerable savings may be possible.

A. Hectograph or offset duplication: May be economical for as few as five or six copies per master; frequently best if ten or more copies are required. Hectograph duplication generally costs more per sheet but less per master than offset duplication because of differences in materials and in per-master time elements of machine operation. Differences in master preparation and readability of copy favor offset duplication. Offset machines are considerably more expensive and require somewhat more technical knowledge to operate. Preprinting static data and lines on masters is simpler and less expensive for offset duplication.

B. Photoprint reproduction: Most appropriate for two to four copies per master. May be economical for up to six or eight copies. Masters may be preprinted by either offset or letterpress methods. Reproduction cost per master is low; unit cost of copies is relatively high. Particularly useful for complex report forms of limited distribution. Affords considerable savings for cumulative reports, particularly graphs, which are brought up to date and reissued periodically. Machine is relatively expensive, requires some technical knowledge to operate and maintain, but is useful for other purposes, such as copying letters and documents and reproducing drawings.

Various combinations of multiple-copy methods are possible. For example, a pre-printed offset or hectograph master may be included as the last copy of a unit carbon set, thus providing any desired number of duplicated copies in addition to those produced by the original writing. Another possibility is to specify one copy of a unit set to be photo-reproducible so that extra copies may be made for special cases. This is also good insurance against obsolescence if there is any doubt about the number of copies needed.

Other types of forms for special writing conditions and uses include the following:

1. Tags—single or multiple copy, one-piece or perforated, and various combinations and special types.
2. Ledger sheets—for hand or machine posting; for vertical, visible-margin, or binder filing.
3. Card forms—for handwritten reports, posting and reference records, hand or machine sorting and tabulating, and other purposes requiring heavy stock.

*See Art. 12 for technical descriptions of the common duplicating processes.

4. Adhesive labels—gummed or pressure sensitive, single or continuous.

11.3.4 Determine the items of information. A form carries two classes of information—static and variable.

1. *Static information* is that which is pre-printed in the manufacture of the form. It is therefore fixed by the design of the form. Static information includes the title, captions, instructions, lines, and art work. In a sense, color, size, and other physical characteristics of different copies of a multiple set are also static information.

It is the static information which the designer must plan, arrange, and specify. The purposes of this static data are to instruct the writer concerning what variable information should be recorded and in what manner and to fix the location of items of variable information and identify them for the users. Roughly speaking, the costs of static data are not important since this information is in effect written only once. Clarity is more important than being concise and minimizing space.

2. *Variable information* is that which is to be written separately on each copy or set. This is the useful information which is required in the system operations. It is essentially the purpose of the form. Obviously, in designing a form, the variable information should be planned first. Then the static data should be devised so as to best facilitate the recording, storing, and use of the variable information. Whereas static data is written only once, variable data is written many times during the life of a form, and is therefore expensive.

Each item of variable information should be clearly defined in regard to meaning, source, derivation, uses and purposes, and ultimate disposition. If these things are not fully understood by the form designer, they are likely to be even less clear to the users—the captions and instructions will tend to be vague, ambiguous, incomplete, or even misleading. The designer must plan this static information to provide clear specifications as to the nature and definition of the variable data and how, where, and when it is to be written on the form.

Each item of variable information must also be justified as being essential, or at least well worth the cost of writing, reading, and using it. The tendency in designing a form is to include marginal items of variable data for vague reasons such as "they might want to know this" or "it may come in handy." Authors of forms also tend to require all conceivable information about each case, without regard to the relative probabilities that the various items will be useful. The cost of such information is a function of the frequency with which it is obtained and recorded, whereas its value depends on the frequency with which it is *used*.

In general, the use value of a variable item of information should be greater than its costs. It has value only if it is used for a worthwhile purpose. It should contribute significantly to the effective functioning of the system in one of the following ways, either as an individual unit of information or in combination with other data:

A. Initiating action by one or more persons.

B. Aiding in planning or control by guiding certain decisions or actions either directly or as reference information.

C. Providing a worth-while check, either by verification or by reconciliation with other data.

D. Being required for a communication or report to another company or to a government agency.

11.4 DESIGNING THE FORM*

To complete the design of a form properly, it must be drawn to scale with all the static information

* Additional references on forms planning and design are: Irvin A. Herrmann, *Office Methods, Systems, and Procedures* (New York: The Ronald Press Company, 1950), pp. 205-519; Gillespie, *Accounting Systems: Procedures and Methods*, especially Chapters 10 and 14; *Handbook of Business Forms*, Editorial Staff, Prentice-Hall, Inc., 1953.

shown in proper size and arrangement. The approach should be:

1. Plan the general arrangement and sequence of information.

2. Decide the exact wording of all captions and instructions.

3. Work out the spacing, line work, and other details of layout.

11.4.1 Writer versus reader. The use of any form involves writing information on it and subsequently reading this information and using it. Unless the writers are also the readers, both must be considered in deciding many of the details of the design. The primary objective should be to provide maximum assurance that the proper information will be recorded in the proper manner and will be interpreted and used correctly. At the same time, the total cost of writing and using the variable information should be minimized; time and convenience for the writer should not be sacrificed for that of the reader, and vice versa.

Viewed with respect to writer and reader, there are two extreme classes of forms:

1. *Class A Forms*—Made out by many people, who may be unacquainted with the form, to transmit information to a central point of use. Such forms are typically handwritten by many different persons at many different places under a variety of conditions. Their general purpose is to gather information and funnel it into a system to be read and used by skilled personnel. Examples of Class A forms are employment applications, time reports, and income tax returns.

2. *Class Z Forms*—Made out by one person and distributed to many readers. Typically, such forms are written by machine by a skilled person who is fully familiar with the information to be recorded and are sent to one or more persons who may be unacquainted with the form. Examples of Class Z forms are invoices, purchase orders, and voucher pay checks.

Clearly, the main problem connected with a Class A form is to get the many individual writers to record the varied information properly. For a Class Z form, the primary considerations are writing the variable information most economically and making clear to the readers the meaning and significance of this information and what they are to do about it. Completely opposite viewpoints are required in deciding the sequence and location of the variable data and the wording of the static data for these two extreme classes of forms.

11.4.2 Layout. The following rules are generally applicable to the layout of any form, although their relative importance will vary considerably from one form to another.

1. *Make optimum use of area.* Avoid dead space due to blank areas, unnecessary lines, poorly placed and poorly worded titles and captions, unnecessarily wide margins, unnecessary art work, and large type. Allow maximum useful writing space. Reduce the size of the form if practicable. Frequently, forms devised by amateurs can be reduced in size as much as 50 per cent with a net *increase* in the amount of available writing space.

2. *Arrange the information in logical order.* Group related information together. Plan natural sequences for the writer, particularly for Class A forms. Consider the order in which the information is used. If data must be transcribed from other forms and/or from this form to others, speed and accuracy are obtained if the information is in the same sequence and preferably the same relative location. Also, captions and instructions may be simplified without loss of clarity if the information is arranged in logical sequence and grouping.

3. *Place key information at the margins.* In general, identifying and indexing data and information which is referred to frequently should be placed where it can be quickly and easily located. The relative advantages of the four corners and margins of the form depend, of course, on how the form is used and filed.

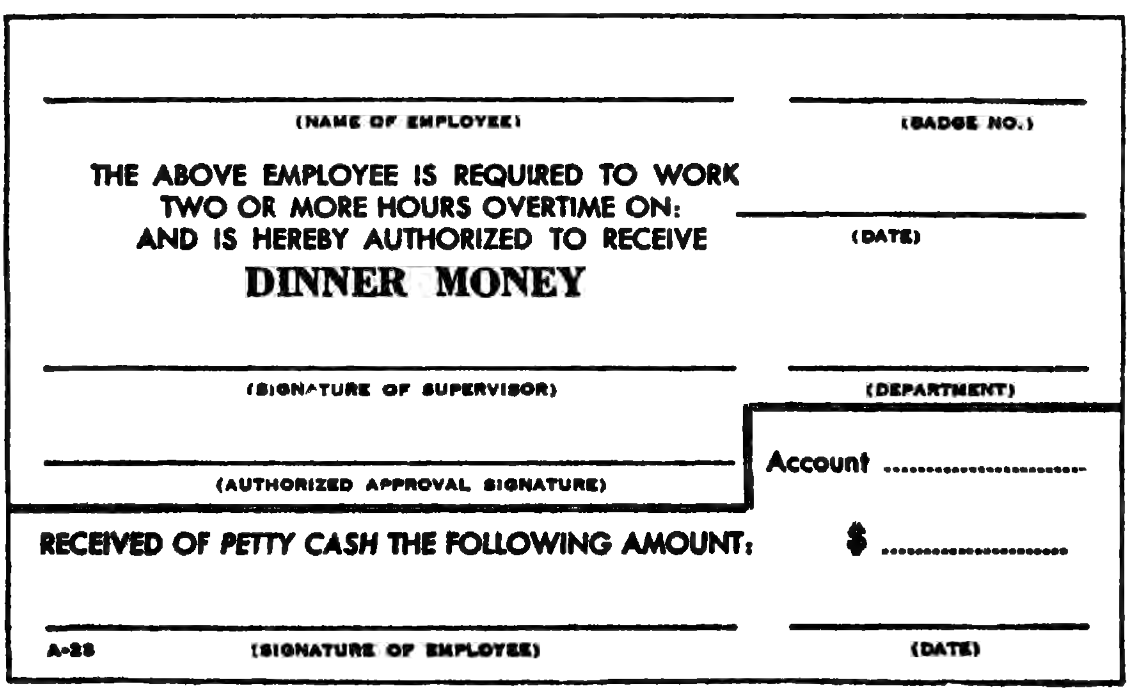
4. *Plan the layout to simplify machine writing.* If the variable data is to be typewritten, the form should be laid out

to minimize typing time. Vertical spacing from the top of the form and between successive lines should be planned to eliminate vertical position adjustments. Variable data should be aligned vertically, utilizing the left margin stop and tabulating stops to minimize visual positioning and the number of horizontal skip spacings.

5. *Plan spacing to suit the writing method.* For typing, use six, three, or two lines per inch vertically, and twelve (or ten) characters per inch horizontally (except for special machines). For longhand, use from one-sixth to one-half inches per line vertically and one-eighth to one-quarter inches per character horizontally, depending on skill of writer and conditions of writing. For type-set forms, vertical spacing should be specified in "points" (approximately 72.2 points per inch).

6. *Avoid useless lines.* The general purpose of lines on a form is to improve

FIG. **6.13** A SIMPLE PRINTED FORM ILLUSTRATING GOOD PLACEMENT OF INDEXING AND POSTING DATA, LOGICAL GROUPING AND NATURAL SEQUENCES OF INFORMATION, EFFICIENT USE OF AREA, ADEQUATE WRITING SPACE (HANDWRITTEN), AND MINIMUM SIZE (STANDARD 3″ x 5″ CARD). NOTE THREE FUNCTIONS OF MAIN PARAGRAPH: IDENTIFYING THE FORM AND ITS PRIMARY PURPOSE, SERVING AS AUTHORIZATION STATEMENT, AND HELPING TO DEFINE ADJACENT ITEMS OF VARIABLE DATA. RECEIPT STATEMENT DEFINES MAIN PURPOSE OF BOTTOM SECTION AND SERVES TO SPECIFY AND IDENTIFY DATA TO BE ENTERED THERE. DOUBLE RULE HELPS INSTRUCT ORIGINATOR AND DIVIDE DATA OF DIFFERENT WRITERS; OTHER LINES ARE ALL FUNCTIONAL.



(NAME OF EMPLOYEE) (BADGE NO.)

THE ABOVE EMPLOYEE IS REQUIRED TO WORK TWO OR MORE HOURS OVERTIME ON: (DATE)
AND IS HEREBY AUTHORIZED TO RECEIVE

DINNER MONEY

(SIGNATURE OF SUPERVISOR) (DEPARTMENT)

(AUTHORIZED APPROVAL SIGNATURE) Account ....

RECEIVED OF PETTY CASH THE FOLLOWING AMOUNT: $ ....

A-28 (SIGNATURE OF EMPLOYEE) (DATE)

the readability of variable information by fixing the position of each item and by segregating adjacent data. Lines are particularly helpful on handwritten forms. However, lines have several disadvantages. They take up space (the heavier the line the greater the area of useless space on each side). Vertical lines are restrictive. Horizontal lines (particularly "leader" lines) may interfere with typewritten data or necessitate frequent vertical adjustment of the machine

11.4.3 Static data. 1. *Captions.* The preprinted captions must serve two purposes—telling the writer what variable data is to be recorded and in what way and identifying the written information for the reader. Obviously, for Class A forms the captions should be primarily instructions to the writer, whereas for Class Z forms, the captions are primarily to identify and explain the variable information. Unfortunately, there is a strong tendency to word the captions with exactly the opposite point of view in each case. Consequently, many Class A forms are confusing to the people who make them out, and the information reported is frequently misleading and unreliable. Conversely, many Class Z forms are confusing and difficult for the recipients to decipher.

Most of the forms used internally in an organization are neither Class A nor Class Z, but fall somewhere in between. (See Fig. 6.12, Art. 10.3.5.) Here, it is necessary to anticipate the problems of the people deriving and recording the information, and to devise captions that serve both to instruct the writer fully and to identify clearly the written information for the readers. The captions should be complete, specific, and well-chosen.

2. *Instructions.* It is often desirable to preprint on the form instructions about filling it out or using and distributing the copies. This is particularly appropriate for Class A forms and frequently for Class Z forms. Such instruction should be clear, complete, and as concise as possible. They should be written for the person to whom they are directed.

3. *Form identification.* Most forms should carry a title. On Class A or Class Z forms, the title should be prominent; on intermediate forms (for example, one writer and one reader) the title is incidental and may sometimes be omitted. There is a strong tendency to place the title in large letters across the top center of the form. Except for certain Class Z forms, it is often better to place key items of variable information in this valuable space and locate the title elsewhere. Each form should carry a form number to provide a positive identification of the form, an abbreviated reference code, and possibly special information, such as date printed, quantity, type or class of form, or department using the form most often. The company name, trademark, address, and phone number should usually appear on forms which are sent outside the company but should be omitted on internal forms.

4. *Copy identification.* For multiple-copy forms it is generally desirable to identify each copy of the set in one or more of the following ways: by color of paper, by copy-number designation, and by end-use department name.

5. *Serial number.* Serial numbering costs very little or nothing on printed forms. If serial numbers are not required for a control purpose, they may nevertheless be very helpful for abbreviated reference to particular issues of the form in correspondence and conversation or on related forms.

6. *Static data should be less prominent than variable data.* The variable information written on a form is that which is useful to the reader. It should be readily distinguishable from the static information; it should stand out and be easy to locate and read. Thus, the static information should be printed in relatively small, light-faced type. If the variable data is to be typed, the static data should not be in the same type face and color.

11.4.4 Duplicating or purchasing specifications. The final step in designing a form should be to supplement the drawing of the form with written specifications covering type of form, number

and sequence of copies, weight and grade of paper, color of ink, punching and perforating, serial numbering, quantity, packaging, delivery date, whether or not a proof is desired, and other instructions.

11.5 DESIGN OF ADMINISTRATIVE CONTROL REPORTS

A basic device for administrative control is a report which compares results against plans and points out significant deviations, undesirable trends, and system trouble. The general purpose of a control report is to initiate corrective and preventive action and adjustment of plans as necessary to insure optimum conduct of some phase of the organization's activities. Such reports are an extremely valuable management tool if they are properly designed. Unfortunately, many are not. Following are some of the things that should be kept in mind when designing or redesigning an administrative control report.

11.5.1 A control report must initiate useful action. Unless the periodic issuing of a control report results in the correction of errors or failures, unsatisfactory performance, operating plans which are no longer appropriate, or standing plans which are no longer suitable, nothing is accomplished by preparing and reading the report.

If a report is to initiate useful action effectively, the following things are necessary.

1. *It must go to the proper person.* First, the recipient must be endowed with sufficient authority to take effective action on problems disclosed by the report. Also, the recipient must be directly responsible for the activities to which the report relates. In general, then, a control report should go to a person in the proper branch and at the proper level of the organization who can and will do something about the differences, trends, and points of trouble indicated by the report. Conversely, it is important that the report be so designed that things which are not within the control of the recipient are segregated from those which are.

2. *It must be read and interpreted properly.* In order to be read at all, a report must be logical, well organized, and self-explanatory. It must be interesting and to the point. It should contain only essential information. The higher the level in the organization to which it goes, the more concise it should be. To be interpreted properly, the terminology used in the report must be appropriate and definite.

3. *It must clearly point out the need for action.* In addition to reporting current results, a control report should provide a comparison with prior plans (for example, previous estimate, budget, schedule, or other predetermined standard); or if this is not practicable, present results may be compared with past results. The report should be designed to point out differences and exceptions and to aid in their evaluation. Significant deviations should be made to stand out clearly from other data by the format of the report. Thus the principle of management by exception should be applied in the design of control reports so that those things most needing attention are corrected and improved.

11.5.2 A control report should serve specific objectives. A control report may be well arranged, logical, and interesting to read, yet fail to initiate any positive useful action. One cause of this is failure on the part of the author to define clearly the objectives of the report in terms of the specific kinds of actions it is intended to stimulate. A related cause is trying to make one report serve too many purposes. A general-purpose report usually falls short of being a satisfactory administrative control device, and becomes merely a means of distributing information.

11.5.3 Some desirable attributes for control reports. 1. *Accuracy.* Unless the reader has confidence in the reliability of the information presented in the report, either its effectiveness will be impaired or it will fall into disuse. In general, this problem of accuracy of information is a matter of properly designing the procedures, work methods,

and forms used in obtaining and compiling the data for the report.

2. *Standardization.* The more familiar the reader is with the report, the more effective it will be. Thus, reading speed and comprehension are improved if successive issues of the report are standardized with respect to arrangement and terminology. It is even desirable to be consistent about such things as color of paper, size, and other factors of appearance. More importantly, the nature and derivation of the information presented should be consistent from one issue to the next, not only for reader acceptance, but also to minimize the possibility of misinterpretation of the data.

3. *Integration.* Ideally, each control report produced by the administrative systems of an organization should be an integral part of an over-all plan for coordination and control. Reports should not overlap; they should complement and supplement one another. Highly condensed summary reports should agree with and tie into more detailed subsidiary reports. The data of reports issued from different departments (for example, cost accounting and production control) should be compatible. If possible, related reports should be on a comparable time basis. Also, of course, terminologies, definitions, and classifications should be consistent for all reports.

4. *Frequency and time lag.* Timing is important. First, a periodic report should be issued at appropriate intervals. This is a question of balance between the costs of preparation and use and the relative value of more frequent or less frequent publication. If a report is issued too frequently, its real benefit may actually decline; if it is not issued often enough, efforts to adjust and improve it may be unduly delayed on the average and in some cases opportunities may be lost.

A control report should be issued regularly and as promptly as possible. In general, the value of a control report declines rapidly with age. It is not uncommon to find reports which are so obsolete at the time of delivery that the entire process of compiling and issuing them is worthless ritual. Thus the time lag between the close of the reporting period (or other controlling event) and the reading of the report should be as small as possible on the average and should not vary significantly from one issue to the next.

5. *Cost.* The total cost of compiling, publishing, distributing, and reading the report should be minimized and must be less than the value of the benefits it produces. Often, in the interests of low cost and speed, a typewritten report should be produced on a preprinted form, and in many cases typewriting should be replaced with handwriting.

11.5.4 Some other classes of reports. Some reports are not *control* reports because they are not designed to initiate useful action. However, many such reports are worthwhile because they transmit information which is used by the recipient in making plans and decisions and guiding future action. Unfortunately, there are also many of these "information" reports which are unnecessary when looked at from the over-all company point of view. This is also true of extra copies of control reports and of necessary information reports.

Many reports are requested and read religiously out of curiosity. Others which are not read are received and filed "just in case" or "for future reference." In other cases, reports are compiled essentially to achieve publicity and recognition for the originating department. Such reports are usually prepared in multiple copy and widely distributed. Although the effort of the originator may be well intended, the result is often useless expense which should be eliminated.

12. SYSTEM METHODS AND DEVICES*

The costs of performing the necessary repetitive tasks of a system depend on the work methods, which in

* Much of the material for this article was compiled and prepared for publication by Creed H. Jenkins, Procedures Analyst, Varian Associates.

turn depend on the devices with which the people work. Part of the job of the system designer is to devise or select the tools of the system. These may range from forms through furniture and filing equipment to complex mechanical and electronic machines.

Standard commercially available equipment is generally more economical in the long run than home-made equipment. However, it should be noted that the only inherent advantage of standard equipment lies in the cost of acquisition and maintenance. Frequently, a special purpose device can be designed which is far superior with respect to labor savings and/or providing assurance against system failures. (See Figs. 6.20 and 6.24 for examples.) One common mistake is to purchase or rent a complete "system" of standard commercial equipment and allow the work methods to be determined wholly by the requirements of the equipment and the recommendations of the salesmen. Unless the work of the system consists of very commonplace tasks, such as in billing or payroll functions or in library operations, these "equipment systems" frequently fail to satisfy fully the system requirements or to provide an acceptable approximation of minimum cost. The proper approach is to consider items of commercially available equipment as potentially useful tools and to work out alternative methods of performing the necessary tasks, using these devices in various combinations to the best advantage.

The objective of this article is to provide a starting point for ideas about alternative methods of performing system tasks. The plan is to describe some of the common types of equipment and to point out how they work, what they can be expected to do, and the principles of system and procedure which they implement.

12.1 INFORMATION ACCUMULATING AND STORAGE METHODS

The cost factors to be considered in selecting equipment for a large volume record keeping problem are:

1. Cost of clerical labor for adding, deleting, finding, reading, and using record information.

2. Cost of equipment, including costs of capital recovery, return on investment, insurance, property taxes, and office space.

3. Costs of supplies and equipment maintenance and operation.

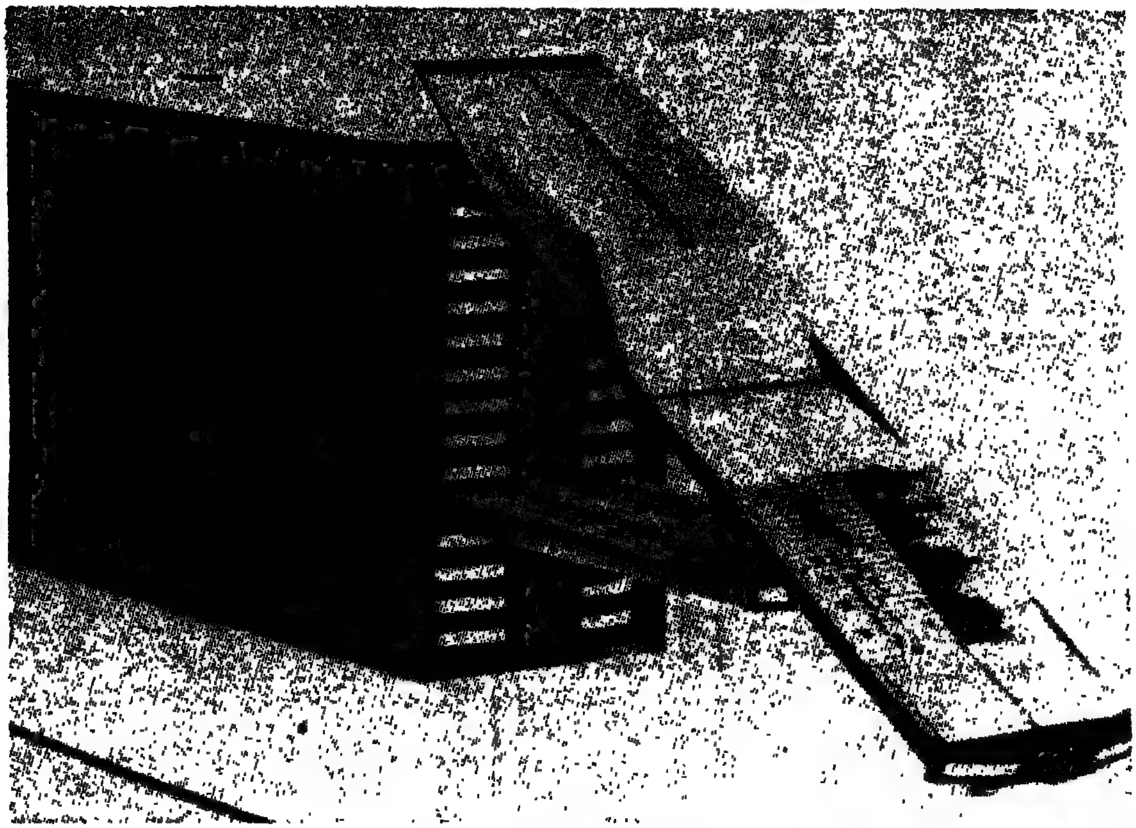
Ordinarily, the more expensive equipment involves concurrently higher operating costs, and must be justified by savings in labor costs. The potential labor savings depend, of course, on the number of record items, the amount of information recorded for each, the frequency with which record items are added and removed, and the frequencies with which the information is posted and used.

Many record keeping problems involve a decision between a multiple-item record (listing method) and a single-item record (individual card or sheet for each unit item). In general, list-type records are seldom satisfactory if the number and sequence of items is subject to change by additions and/or removals. As compared to a deck of individual cards or sheets, which can be arranged in any classification and sequence and may be expanded or contracted readily, a list-type record is relatively inflexible. Ordinarily, an individual-item record costs more to create, but is likely to be easier to maintain and to be more useful. The types of equipment described below employ the single-item principle.

12.1.1 Posting record equipment. The primary requirement for an item-by-item record to which information must be posted frequently is *speed*—speed in finding a given unit record, positioning it for use, reading it, writing on it, and putting it away.

1. *Visible margin files:* The basic characteristic of visible margin equipment is that the unit records are filed in groups (of 5 to 100), and are fanned so that one margin (or two) of each card or sheet in the group is exposed for quick location and identification.

A. Tray files: Unit records are retained in hinged-leaf fashion. Bottom



Courtesy of The Wassell Organization.

FIG. **6.14** LEAF-TYPE VISIBLE MARGIN TRAY FILE.

margin visible. To post or read, clerk selects cabinet, selects and pulls out tray, and locates and lifts leaves covering desired unit record. (See Fig. 6.14.)

B. Tub files: Unit records are filed vertically, held in place by gravity, and positioned horizontally by notches in bottom edge. Side or angle-corner margin is visible. To post or read, clerk selects bin, spreads file at proper section, and removes unit record to writing surface. File remains open for reinsertion. (See Fig. 6.15.)

C. Loose-leaf books: Unit records held in offset positions by uniformly spaced posts or rings. Top or bottom margin visible. To post or read, clerk selects book, opens to proper divider, and lifts sheets covering desired unit record. Particularly suitable for a small or moderate number of items.

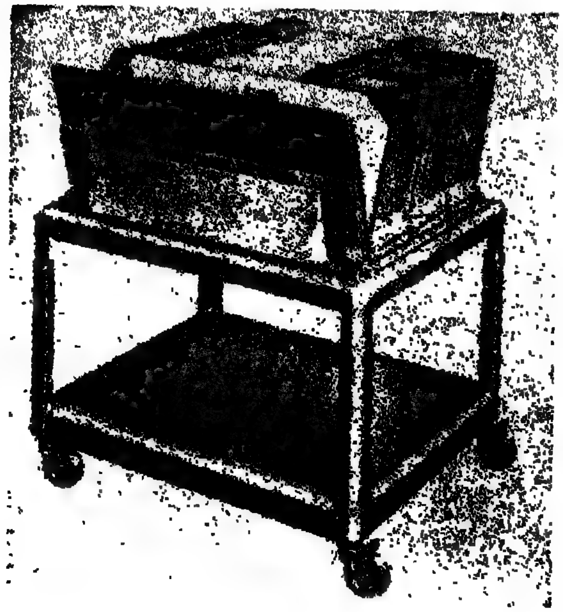
In all types of visible margin files, unit records may be readily removed or added. Periodically, unit records must be transferred between sections to accommodate new items and consolidate depleted sections.

2. *In-line files:* The common types of in-line files are the ordinary vertical-bin letter and card files, loose-leaf books, and rotary wheel files. Index tab dividers identify sections and sub-sections. To locate an item within a sub-section, the unit records must be separated manually.* With loose-leaf and wheel types, posting and reading may be done with the unit record in place. See Fig. 6.16.

12.1.2 Reference record equipment. Where information must be stored for potential or periodic future use, without the necessity of posting additional information to the unit records, the objectives are to achieve speed in finding, using, and re-filing, and to save office space.

Any of the above posting record equipment may be used for reference

* For vertical-bin files, cards are available with built-in magnetic strips which spread them apart to facilitate selection.



Gillespie, *Accounting Systems: Procedures and Methods*, p. 320.

FIG. **6.15a** VERTICAL-TYPE VISIBLE MARGIN TUB FILE.

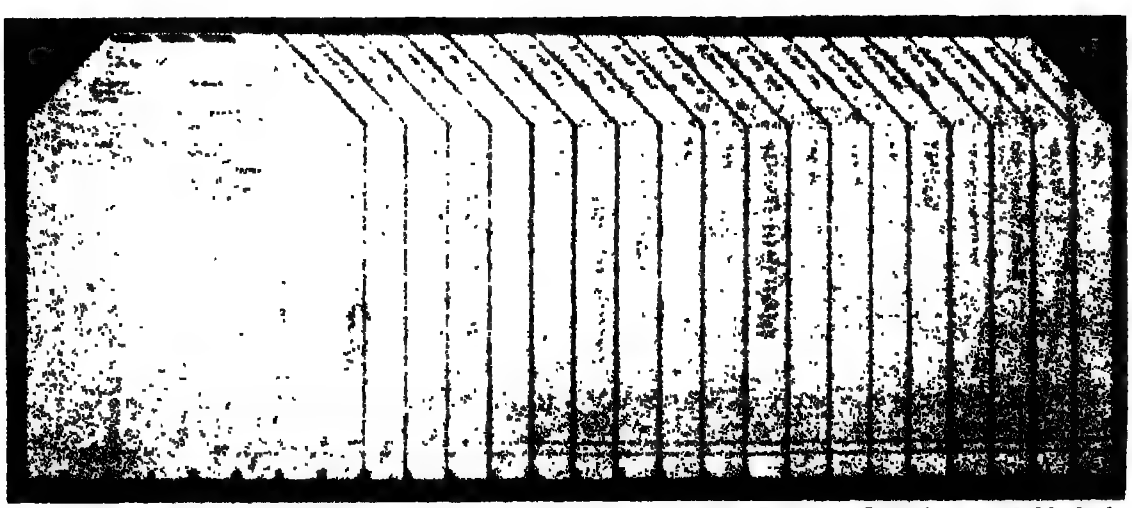
records. But in this case, except for loose-leaf books, the extra cost of a visible-margin file over an in-line file is not justified as frequently as when posting is required. Small-card wheel files and magnetic-card vertical files are well suited for reference applications.

Because the writing requirement is eliminated for reference records, there are many more alternatives of method and equipment, such as:

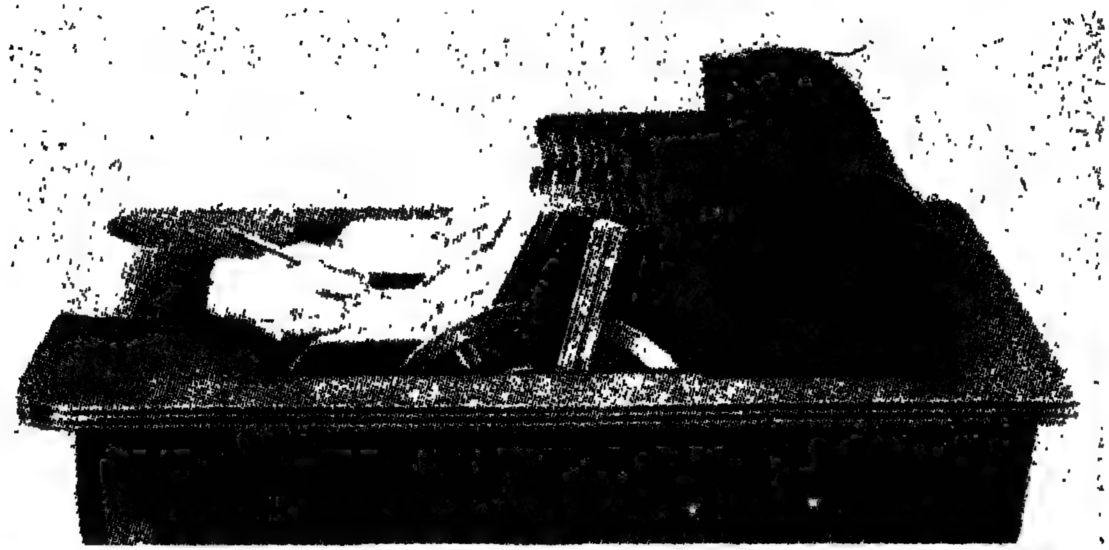
1. *Strip-record boards.* Item records are written on a perforated strip form, separated, and placed in a frame in proper sequence. Each unit record in the frame is entirely visible. Frames are usually hinge-mounted on a fixed or rotary holder. Suitable where record required for each item is brief and of standard form.

2. *Folder-and-guide files.* This classification includes all the common vertical

FIG. **6.15b** SET OF RECORD FORMS FOR VISIBLE MARGIN TUB FILE.



Gillespie, *Accounting Systems: Procedures and Methods*, p. 319.



Courtesy of Wheeldex & Simpla Products, Inc.

FIG. **6.16** A WHEEL-TYPE IN-LINE FILE SUITABLE FOR POSTING RECORDS.

in-line file methods and equipment. Widely applicable for records which are not referred to often and particularly for paper documents of letter size or mixed sizes.

3. *Racks and clip boards.* For temporary filing of standard sized cards or slips with each item or small group of items visible for quick reference or use. Figure 6.17 illustrates a type of clipboard file which is available commercially.

4. *Microfilming.* Essentially a means of copying original documents and storing the information (and facsimile) in compact, durable form. Most applicable for storing long-retention records, for copying documents which cannot be retained, and for transmitting large volumes of written material long distances.

5. *Sound and code recording.* Information may be recorded in oral form for subsequent transcription or reference either magnetically, on tape or drum, or mechanically, on plastic disk, band, or drum. Coded information may be recorded in the same ways or on punched cards or punched tape for subsequent input into mechanical or electrical devices for interpreting, computing, tabulating, or repetitive reproduction.

12.2 WORK PLANNING AND PROGRESS CONTROL DEVICES

12.2.1 Definitions. To select or design intelligently a device to aid in planning and/or controlling repetitive work, it is first necessary to have a clear idea of the functional purposes the device is to serve. Therefore, it is helpful to break down the general area of work planning and control into more specific administrative functions and to define some terminologies as follows:

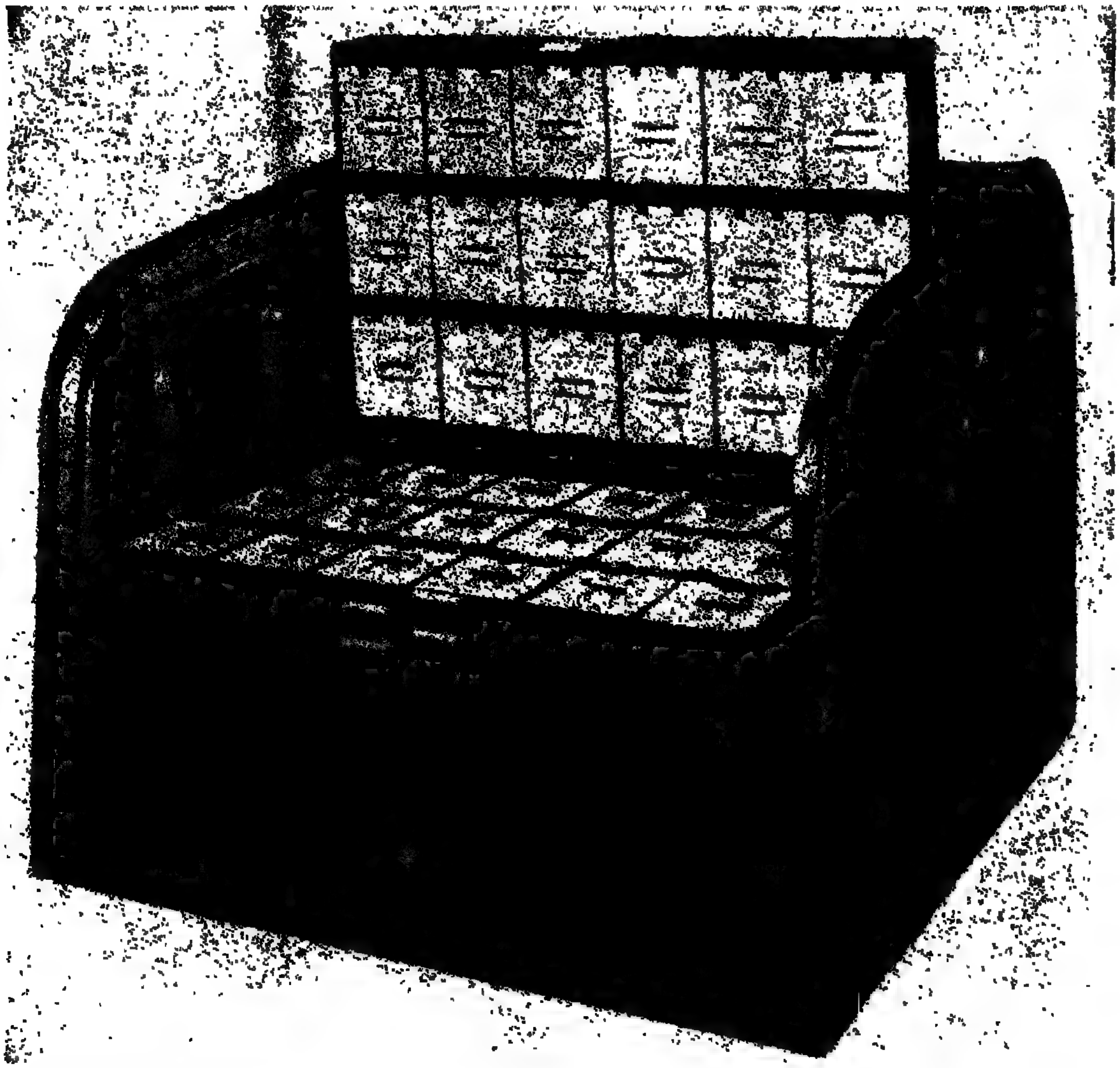
1. *Load planning:* Deciding upon the assignment of tasks to departments, men, machines, plants, or contractors, and determining the sequence in which the tasks assigned to each unit will be performed. This involves developing alternatives of work assignment, load, and sequence and deciding between these alternatives.

2. *Scheduling:* Detailed planning of work with respect to time. In addition to load planning, may include any or all of the following:

A. Establishing deadlines for starting and finishing tasks.

B. Planning the coordination of various tasks.

C. Planning the utilization of avail-



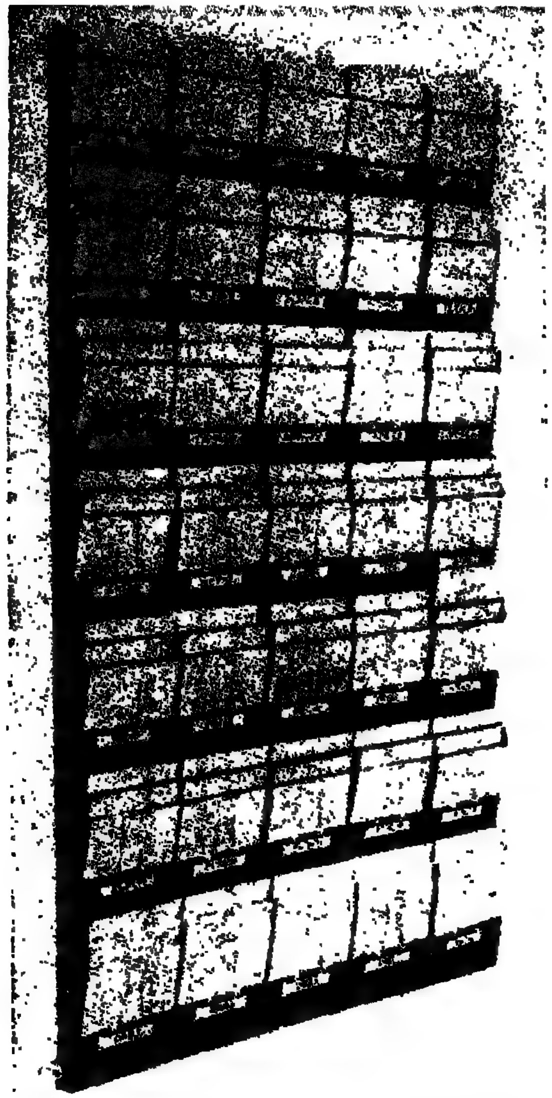
Courtesy of Industrial Division, The McCaskey Register Company.

FIG. 6.17 AN EXAMPLE OF A CLIP-BOARD TYPE OF FILE.

able time of men and machines individually or by groups.

3. *Progress control:* Involves comparing results against plans when both are related to time, for the purpose of directing supervisory effort to significant deviations which require corrective action. Progress may be compared with formal projected plans, as when progress control is coupled with load planning or scheduling, or may be compared with past performance or current average performance.

12.2.2 Selecting work planning and progress control devices. The primary purpose of a device for use in work planning and/or progress control should be to implement satisfactory performance of the desired administrative tasks. Thus, a load planning or scheduling device should be a means of improving the chances that the plans which are developed will work satisfactorily and of helping to prevent or disclose inconsistencies, conflicts, omissions, and other planning mistakes. A progress control device must systematically provide a useful comparison of current status against plans in such a way as to help prevent oversights and failures to take necessary corrective action. In general, a device for any of these purposes is more effective



Courtesy of Industrial Division, The McCaskey Register Company.

FIG. 6.18 EXAMPLE OF A PLANNING AND DISPATCHING RACK.

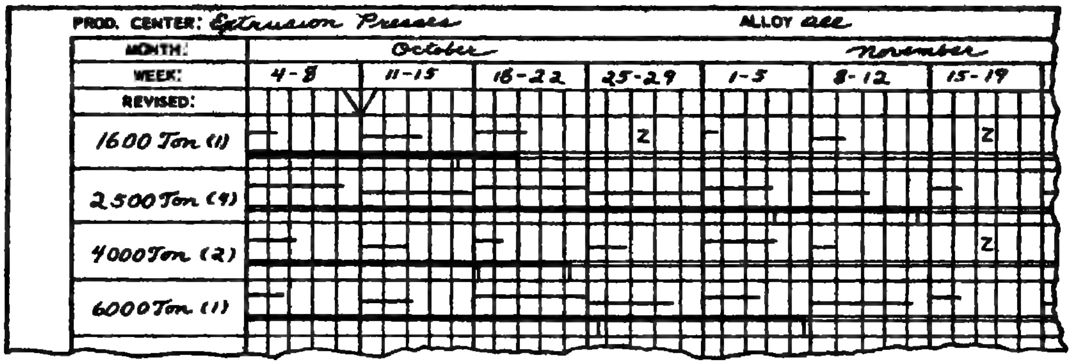
if it offers a means of visualizing the established plans and critical relationships quickly and comprehensively. Also, of course, it should help to reduce the time and effort required to do the job.

12.2.3 In-line files and racks. The simplest type of work planning device is a file or rack into which cards or slips for the various tasks to be assigned can be sorted and arranged in proper sequence. Frequently, a rack or file used in load planning can also be used to "dispense" the tasks at the place of use. (See Fig. 6.18.) In-line files and racks are generally not suitable for scheduling but may be adapted for progress control (see Art. 12.3.6).

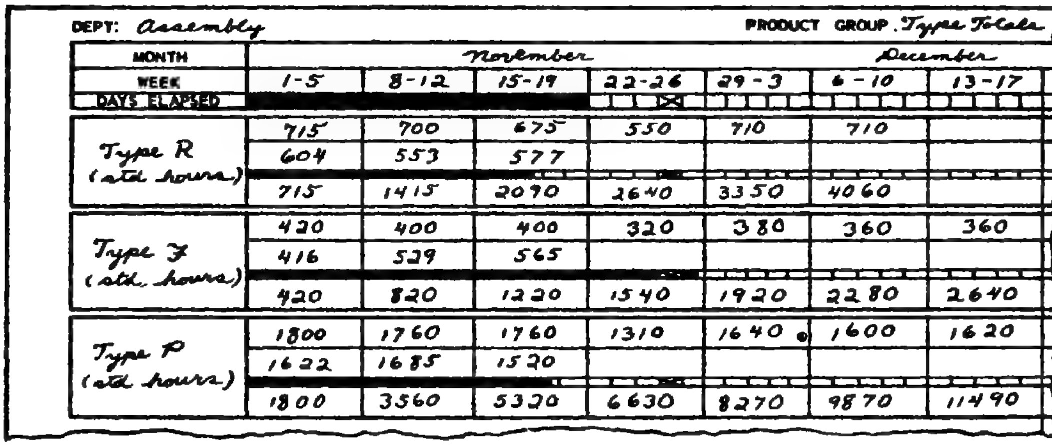
12.2.4 Gantt-type charts. The essential feature of a Gantt-type chart lies in plotting plans and/or progress in relation to time. Charts with this time-scale feature have been devised for a wide variety of applications to load planning, scheduling, and progress control problems. The original charts, developed by Henry L. Gantt, incorporated an ingenious set of techniques and conventions which made it possible to maintain them cumulatively without the necessity of deleting previous informa-

FIG. **6.19a,b,c,d** EXAMPLES OF GANTT-TYPE CHARTS.

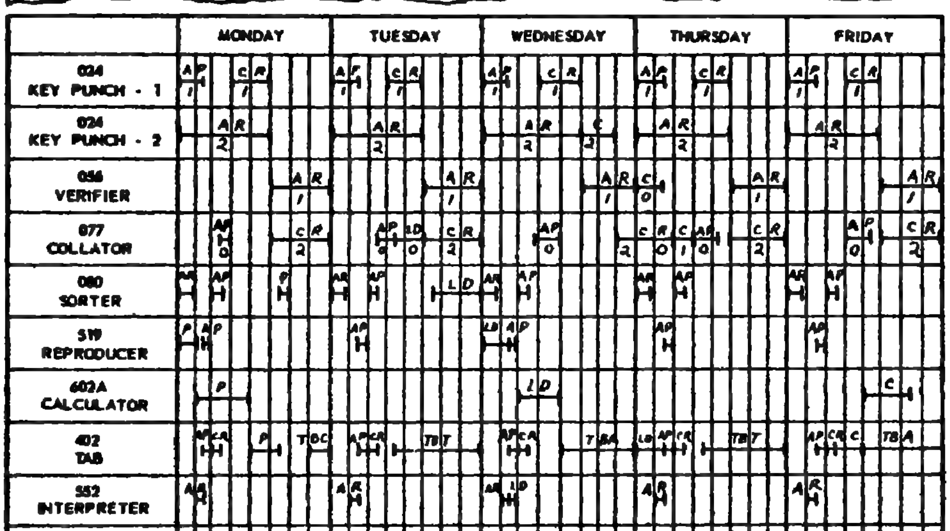
a



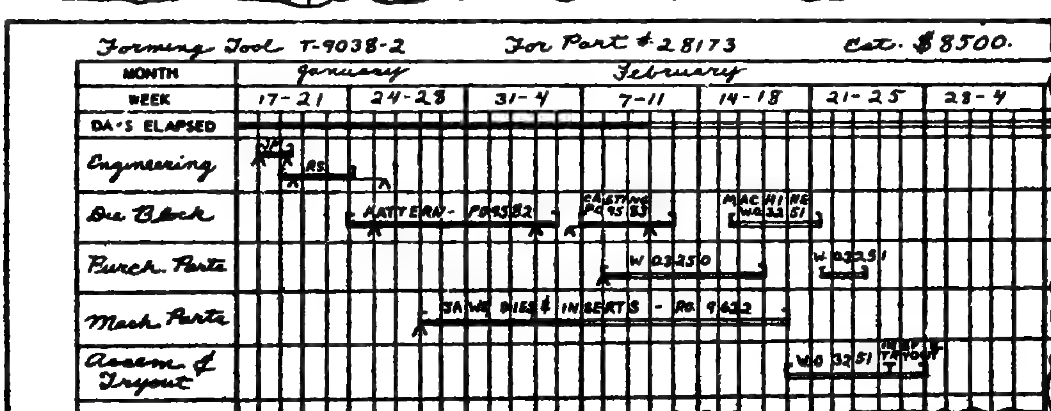
b



c



d



tion.* (See Fig. 6.19 for examples of the basic kinds of Gantt-type charts.)

12.2.5 Track boards. Figure 6.20 illustrates a modern development of the Gantt charts designed to eliminate the labor of drawing, thereby facilitating trial-and-error planning and scheduling, periodic revamping of plans, and frequent posting of progress. Typically, such boards consist of a horizontal track for each machine or unit to which work is to be scheduled. A suitable time scale is marked off horizontally from left to right. For load planning or scheduling, job cards (and possibly set-up time cards) which are cut to time-length may be placed in the tracks in any desired order and position. With the addition of suitable time and progress markers, such boards can be adapted for progress control of either continuous tasks or discrete jobs.

12.2.6 Leaf-type visible margin tray files. Progress control and follow-up initiation can be incorporated with record keeping by using signals and markers available for equipment of this type. (See Fig. 6.21.)

12.2.7 Visible margin leaf boards. The device illustrated in Fig. 6.22 is an adaptation of the leaf-type visible mar-

* See Wallace Clark, *The Gantt Chart* (London: Isaac Pitman and Sons, Ltd., 1947) for detailed information concerning the construction and application of Gantt charts.

6.19a A LOAD PLANNING CHART. SHOWS FOR EACH MACHINE THE WORK AVAILABLE EACH WEEK (LIGHT LINES) AND THE TOTAL BACKLOG (HEAVY LINE).

6.19b A PROGRESS CONTROL CHART FOR A CONTINUING ACTIVITY (DEPARTMENTAL PRODUCTION BY PRODUCT GROUPS). WEEKLY NUMBERS INDICATE WORK SCHEDULED, ACTUAL WORK ACCOMPLISHED, AND CUMULATIVE WORK SCHEDULED. BARS INDICATE CUMULATIVE PROGRESS AGAINST SCHEDULE TO DATE.

6.19c A MACHINE SCHEDULING CHART. SHOWS PLANNED STARTING AND COMPLETION TIME FOR EACH JOB SCHEDULED TO EACH MACHINE. ALSO INDICATES WORK ASSIGNMENT OF (KEY PUNCH) OPERATORS.*

6.19d A JOB SCHEDULING AND PROGRESS CONTROL CHART ILLUSTRATING APPLICATION OF GANTT "LAYOUT" CHART TO COMPLEX TASKS. THIS TYPE OF CHART IS COMMONLY USED FOR FOLLOWING PROGRESS OF JOBS SCHEDULED TO MACHINES.

* Data courtesy of Clark Maxon, I.B.M. Supervisor, Varian Associates.

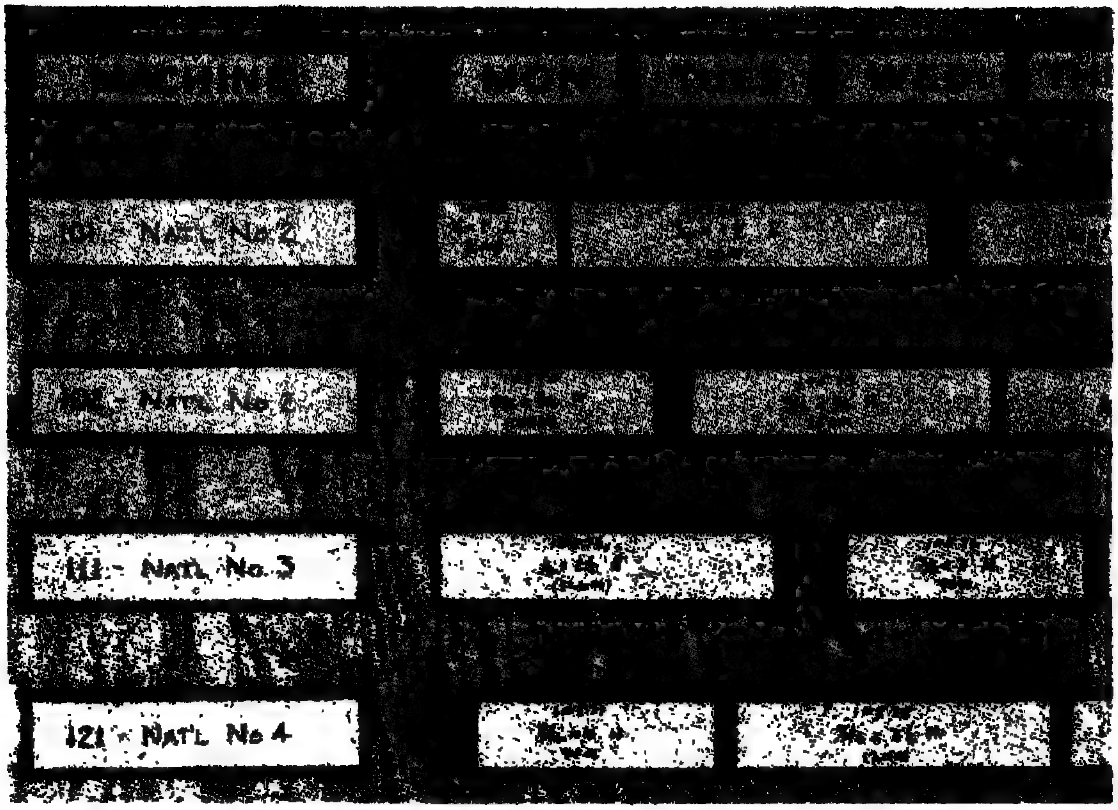
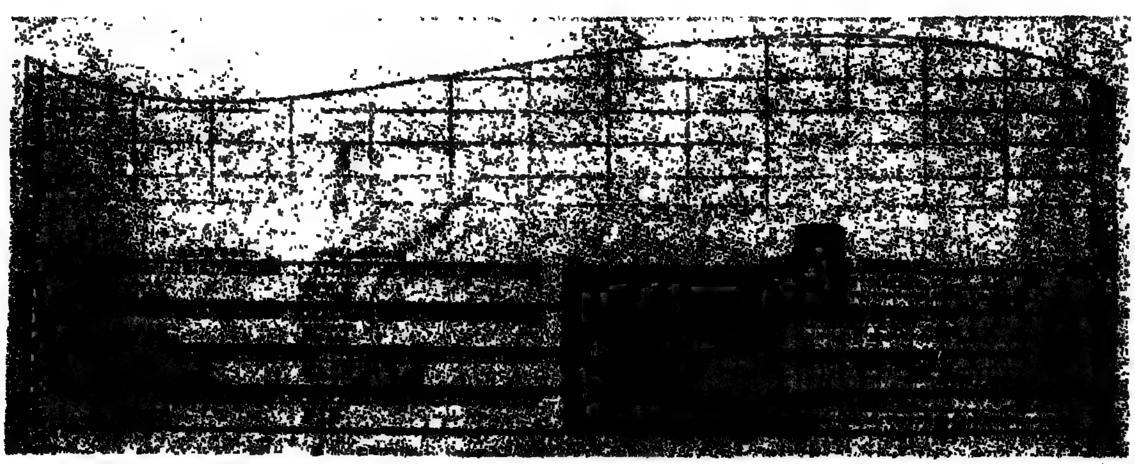


FIG. 6.20 SECTION OF A TRACK BOARD USED FOR MACHINE SCHEDULING. INSERTS BETWEEN JOB STRIPS INDICATE SETUP TIME. TRACKS ARE PRICE TAG MOLDING.

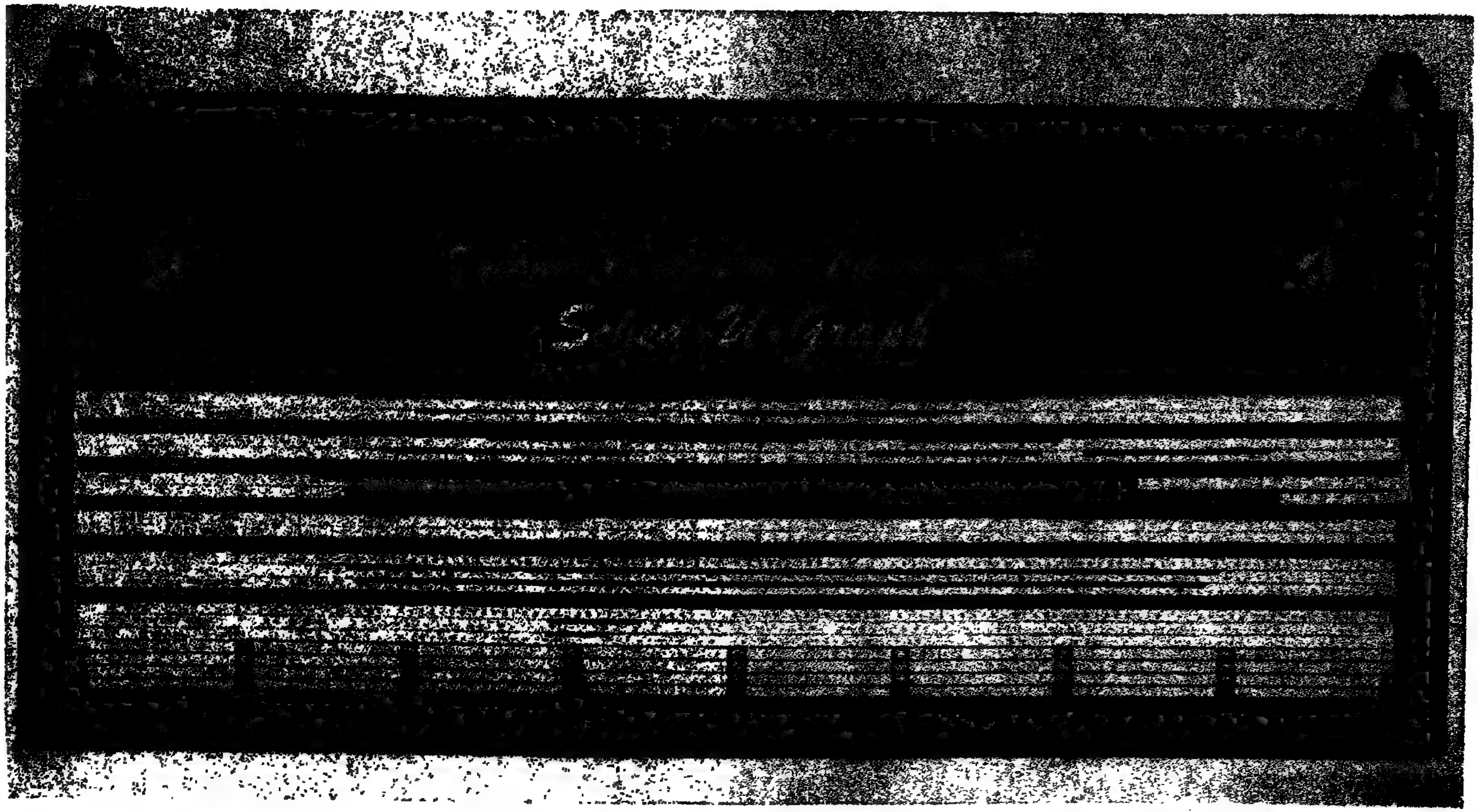
gin file to Gantt chart principles and purposes. It is a highly versatile and effective tool for a wide range of repetitive planning and control problems, readily adaptable for planning and progress control of continuing tasks and particularly suitable for scheduling and progress control of discrete jobs where a large number of machines must be scheduled. Standard equipment of this type is available commercially.

12.2.8 Peg boards. The type of board

FIG. 6.21 EXAMPLE OF THE USE OF SIGNALS AND MARKERS WITH A LEAF-TYPE VISIBLE MARGIN RECORD.

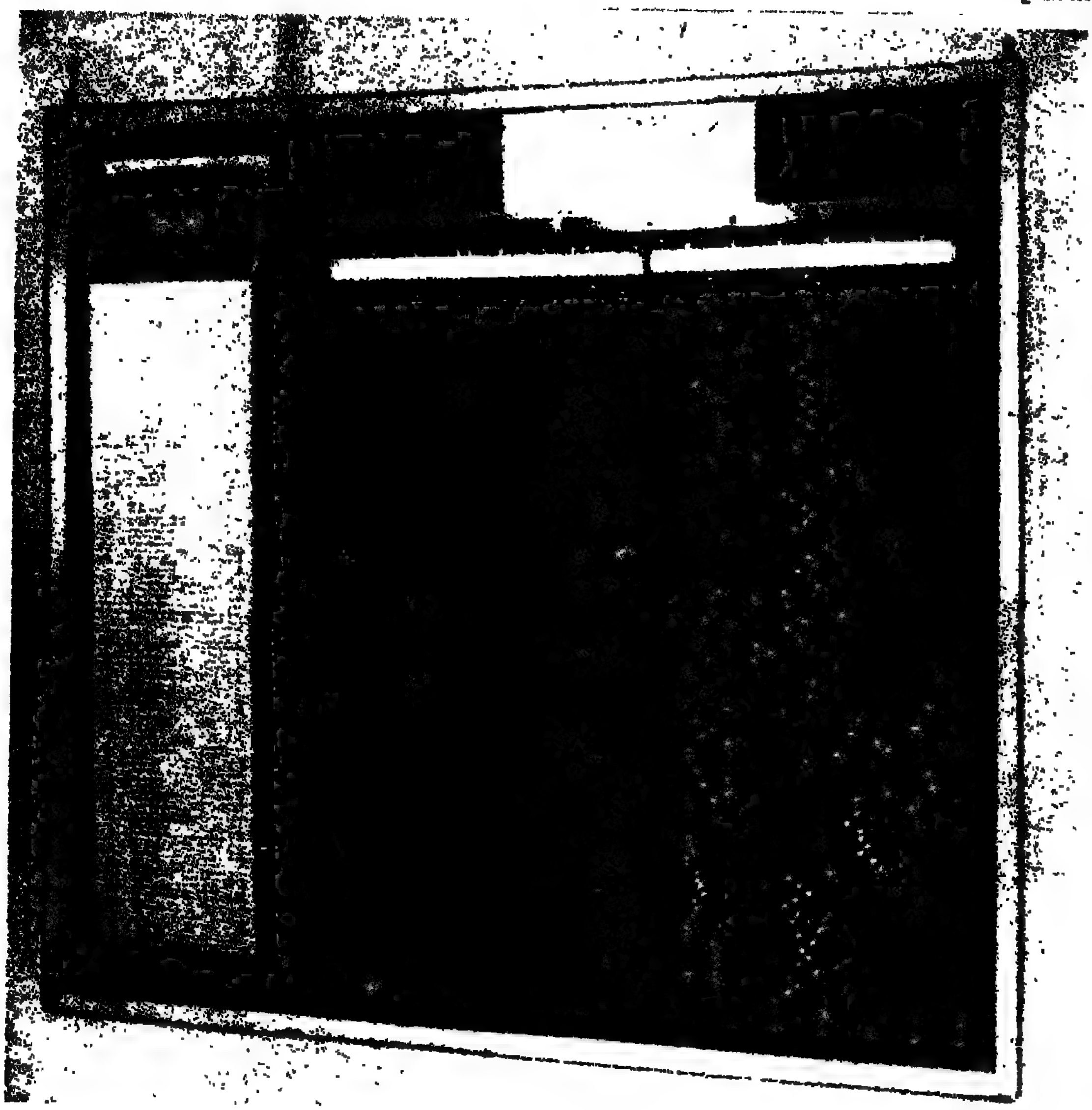


Courtesy of Acme Visible Records, Inc.



Courtesy of Remington Rand, Inc.

FIG. 6.22 DEMONSTRATION SETUP OF A VISIBLE MARGIN LEAF BOARD SHOWING SOME TYPICAL APPLICATIONS OF THIS EQUIPMENT.



Courtesy of The Wassell Organization.

FIG. **6.23** 100-ITEM "PRODUC-TROL" PEG BOARD.

illustrated in Fig. 6.23 is most suitable for load planning and for status or progress control of continuing functions, such as material procurement, standard-process production, and sales evaluation.

12.2.9 Progress status file. Figure 6.24 illustrates a device called a "progress status file" which was designed to facilitate job progress control where detailed scheduling is not practicable. It provides a visual comparison of the progress of any one job with that of similar current jobs. It is particularly applicable to work-in-process expediting and follow-up problems.

12.3 HAND SORTING AND SELECTING DEVICES

12.3.1 Manual sorting aids. Table-top sorting operations are usually good candidates for work simplification. If the sorting cannot be combined with a filing operation, it can often be facilitated with a leaf sorter or special rack. Leaf sorters for classifying and sequencing documents manually are available in a variety of sizes and types (for example, see Fig. 6.25). For many sorting jobs, it may be worth while to design a special rack with labeled pigeon holes, notches, slots, or shelves.

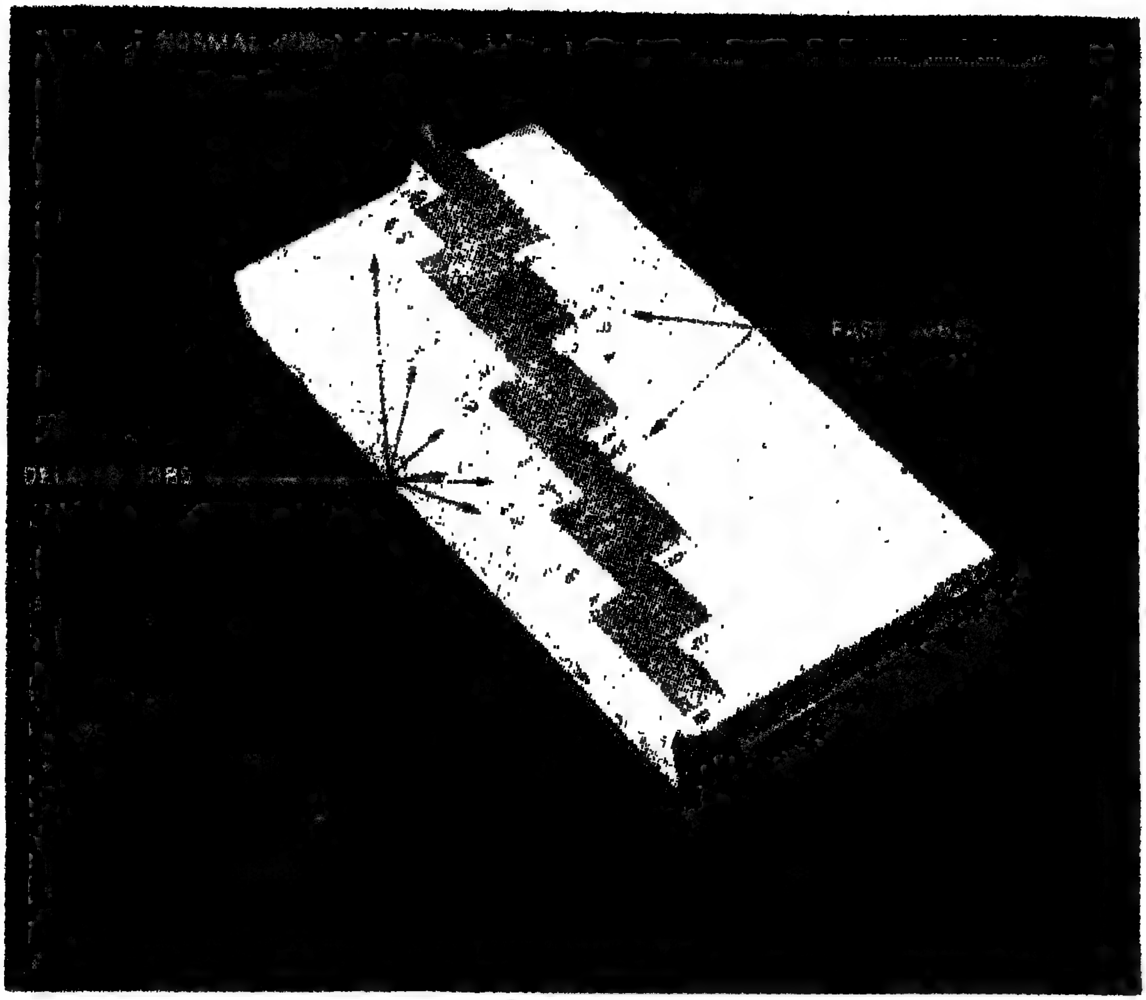
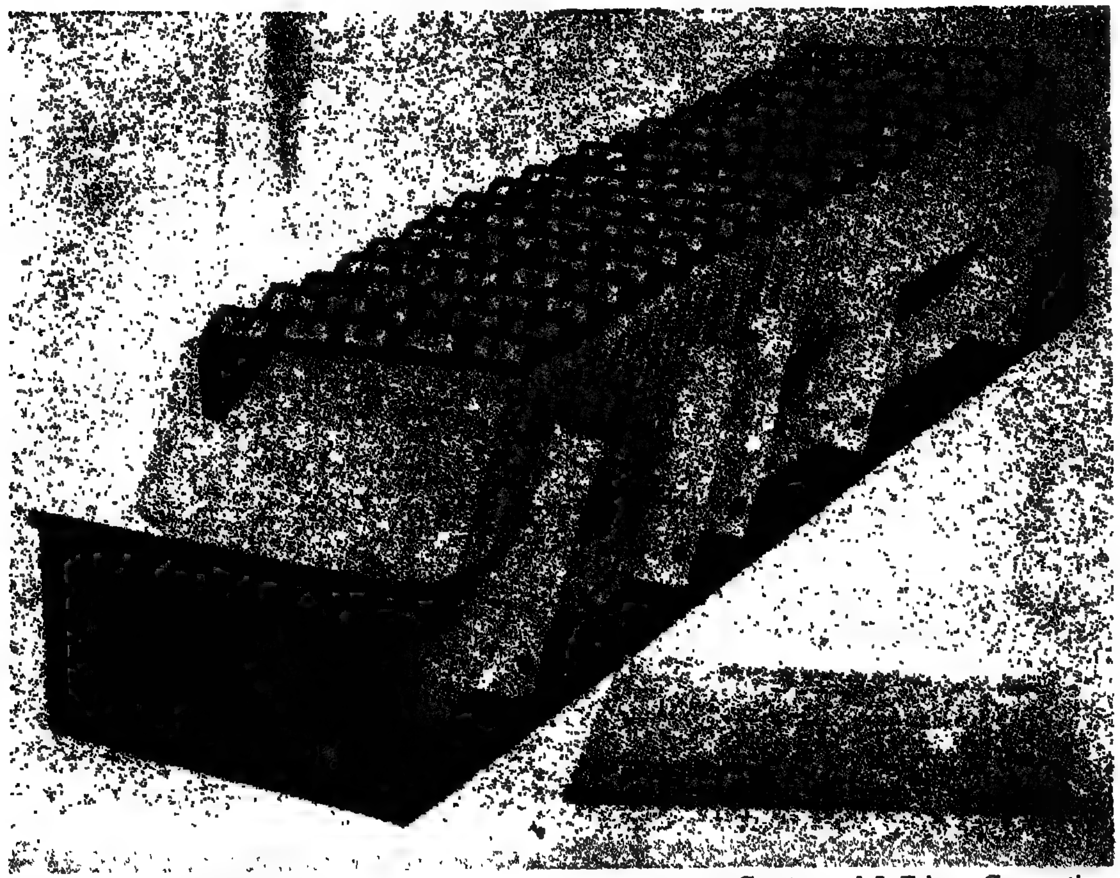


FIG. **6.24** "PROGRESS STATUS FILE." JOB CARDS ARE FILED BY JOB NUMBER (WHICH ARE ASSIGNED CHRONOLOGICALLY BY DATE OF RELEASE). CURRENT LOCATION OF JOB IS SHOWN BY "TAB" CARD PLACED IN FRONT OF JOB CARD. WHEN JOBS ARE REPORTED TRANSFERRED FROM ONE STAGE OF PROCESS TO ANOTHER, THIS INFORMATION IS POSTED TO FILE BY SWITCHING TAB CARDS. (ANY ERROR IN POSTING JOB PROGRESS IS AUTOMATICALLY CORRECTED IN NEXT POSTING.) JOB CARDS MOVE TOWARD REAR OF FILE AS CARDS FOR COMPLETED JOBS ARE REMOVED AND CARDS FOR NEW JOBS ARE ADDED IN FRONT. IF PROGRESS IS NORMAL, JOBS TOWARD THE REAR WILL SHOW TABS TOWARD THE RIGHT SIDE, AND VICE VERSA. JOBS WHICH ARE DELAYED IN RELATION TO THE OTHERS STAND OUT WITH TABS APPEARING IN LEFT REAR AREA OF THE FILE. THE LONGER A JOB IS DELAYED THE MORE IT STANDS OUT. STATUS OF ANY JOB MAY BE READILY DETERMINED.



Courtesy of LeFebure Corporation.

FIG. 6.25 A LEAF-TYPE SORTING AID.

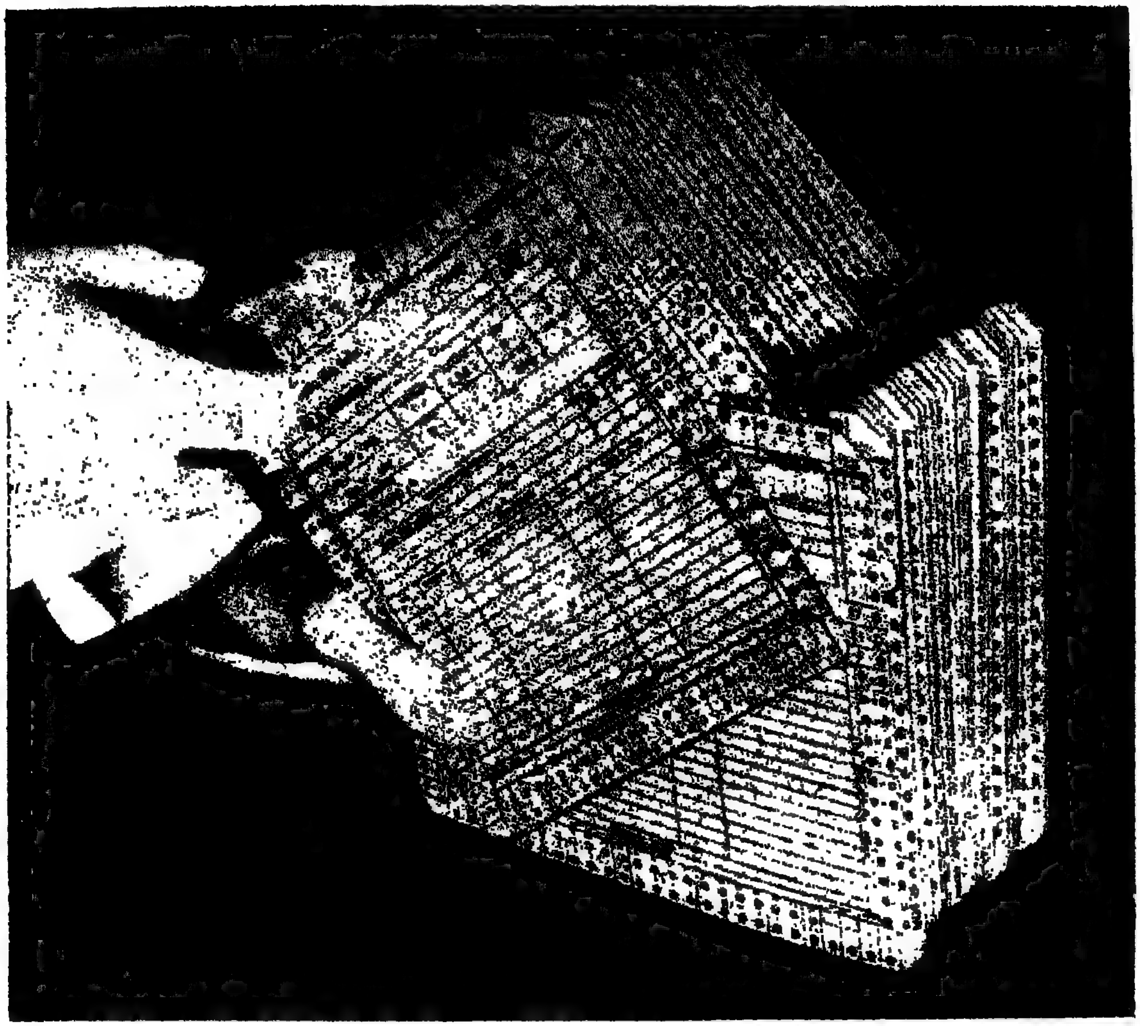
12.3.2 Marginal-punched cards.* If each record item can be written on a card form on which the key classifying data is coded in the form of holes and notches along the margins, the cards can then be selected or sorted mechanically. Cards for this purpose are manufactured with a series of holes along one or more margins. After it is made out, each card is coded by notching out selected holes. Then, if a rod is passed through the set in a given hole position and raised vertically, all cards which are not notched in that position are lifted from the set and those which are notched remain in place (see Fig. 6.26). By proper design of the coding and selecting procedures, required group segregation and sorting operations can be accomplished rapidly with minimum chance of error.

Edge-punched cards are particularly suitable where the same body of interrelated data must successively be sorted and classified three or more times in different ways. Some typical industrial applications are for personnel records, material order planning, production scheduling, and cost distribution. Principal limitations are in the amount of information which can be coded into the number of hole positions available (which depends on card size) and the time and skill required to notch and manipulate the card.

*See Robert S. Casey and James W. Perry, *Punched Cards, Their Application to Science and Industry* (New York: Reinhold Publishing Corp., 1951), for a thorough treatment of punched card principles, techniques, equipment, and applications (particularly edge-punched hand-sort cards).

12.4 AUTOMATIC INFORMATION-PROCESSING MACHINES

Mechanical and electronic machines which will automatically perform such tasks as sorting and collating, comparing and computing, and



Courtesy of the Mcbee Company.

FIG. **6.26** HAND SORTING A SET OF MARGINAL-PUNCHED PERSONNEL RECORD CARDS.

summarizing and printing are rapidly becoming commonplace administrative tools. Ultimately, even small business organizations will find it necessary to employ the services of such machines. Machines which are now economical only for large corporations and government services will be prototypes for simpler, smaller, less complex machines for tasks of lesser magnitude. The larger machines themselves will be improved and be more widely used on a service-center basis.* The reasons are simple:

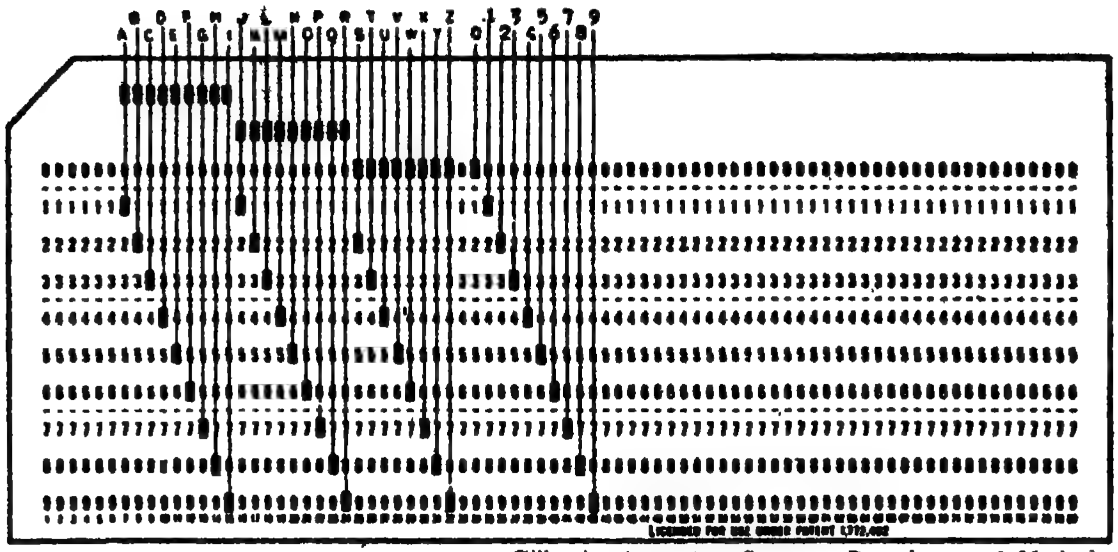
1. For highly repetitive tasks, skilled clerical labor compares less and less favorably each year with machine work, considering costs, availability, and relative reliability.

2. Speed is becoming a more critical requirement. The value of decision-making information which is more current, and of reduced system delay and time lag, is steadily increasing.

3. Many data processing tasks are not practicable on a systematic basis except by automatic machine, yet the demand for better and more frequent analyses, summaries, and computations is growing.

* The problem of transmitting information to and from data processing service centers will perhaps be resolved by direct telegraphic or microwave communication.

12.4.1 Posting and billing machines. A variety of machines are available which perform such elementary automatic operations as selecting, comparing, computing extensions and ratios, and



Gillespie, *Accounting Systems: Procedures and Methods*, p. 685.

FIG. **6.27** HOW INFORMATION IS PUNCHED INTO A CARD (IBM SYSTEM). THIS SAMPLE CARD READS: ABCDEFGHIJKLMNOPQRSTUVWXYZ 0123456789, USING 36 OF 80 AVAILABLE COLUMNS.

writing the results in end-use form. Such machines are most commonly used in special-purpose functions such as accounts payable, payroll, general ledger accounting, cost accounting, and occasionally in systems for materials control and production control.

12.4.2 Punched card machines. The most versatile automatic data processing machines available for industrial systems are the so-called "tabulating machines" which utilize the punched card principle. Each unit set of data to be processed by such equipment is transposed from the written source document to a card in the form of holes made in predetermined locations. (See Fig. 6.27.) The various machines "read" the information on the cards by sensing the presence or absence of a hole (or hand-made mark) at each location.

Automatic operations that can be performed separately or in various combinations by these machines include:

1. Sorting, selecting, merging, and collating.
2. Comparing, matching, and verifying.
3. Copying punched information from a master card to one or more other cards.
4. Counting and calculating.
5. Punching machine results into cards.
6. Transposing hand-marked card data into punched-hole form.
7. Transposing data from punched cards to punched tape, and vice versa.
8. Printing on single and multiple-copy forms, duplication masters, and other types of forms, or onto the machine cards.
9. Typewriting from tape and/or cards.

Machine speeds run as high as 9,000 cards per hour for printing, 12,000 per hour for reproducing, and 25,000 per hour for sorting.

12.4.3 Electronic computers. For ultra high-speed calculating, electronic digital computers have been developed which employ the binary counting system to perform numerical operations. Machines of this type vary from extremely large, complex, and expensive installations which are capable of solving problems not otherwise solved practically, to relatively small general purpose calculators

which are used in conjunction with punched card machines. The former are useful primarily for complex technical and economic problems of very large magnitude (in terms of numerical operations). The latter are suitable for routine calculating in administrative systems, particularly where punched card and/or punched tape machines are employed. For special purpose applications, such as sales stock inventory control, it has proven practical to tally information into the electronic memory of a computer without going through the medium of punched cards or tapes.

12.4.4 Input and output. The key problems for system analysts and equipment manufacturers with respect to the use of present and future automatic data processing machines are the methods of feeding information into the machine with minimum cost and time and of putting out the results in the most economical and practical form. The problem of equipment manufacturers is to develop and make available better equipment and techniques. The problem of the system analysts is to work out satisfactory low-cost procedures and methods for obtaining the data and preparing it for input and for using the machine results.

An ultimate objective which may be attainable in many cases is to eliminate the work of putting the data into written form prior to input and likewise to eliminate output printing of intermediate data which must then be interpreted and acted upon to achieve the desired end results. For a purchased parts inventory, for example, stock receipts and withdrawals might be dialed or punched by the stock clerk directly to the machine, instead of being written on forms, transmitted by messenger, and key punched into cards or tape. On the other side, purchase orders might be printed by the machine automatically, in accordance with standard instructions, whenever dictated by the cumulative transaction data. Administrative effort would then be reduced to reviewing control reports and changing instructions to the machine as necessary.

12.5 DUPLICATION METHODS AND EQUIPMENT

Following are brief descriptions of the most important of the duplicating processes commonly employed in administrative systems for reproducing copies of filled-out forms.

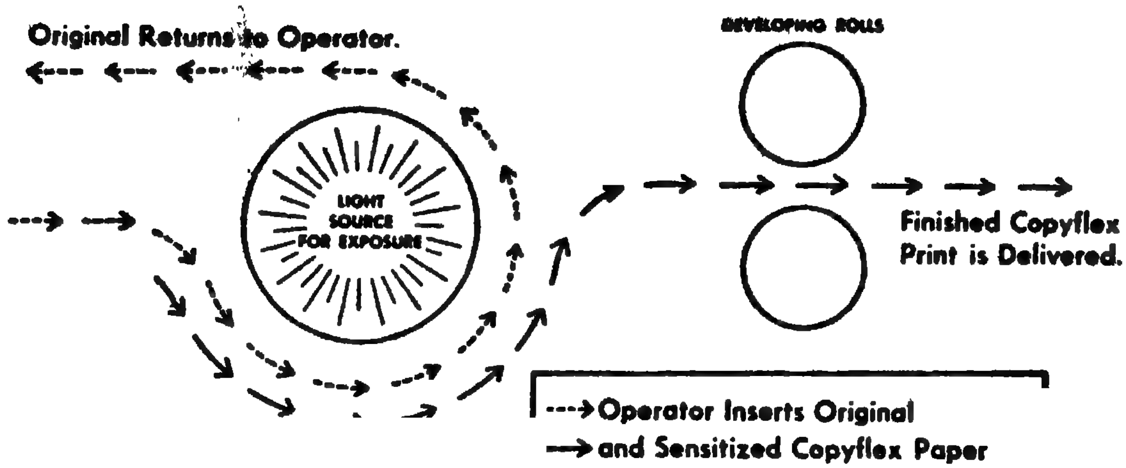
12.5.1 Contact photoprinting. These processes use a photo-sensitized paper which is exposed to intense light and then developed chemically to produce a facsimile of the original copy.

1. *Direct process.* Light passes through master (or document to be reproduced), exposing photo-sensitive surface of sheet. Print is then developed by contact with vapor or liquid agent. (See Fig. 6.28.) Exposure time depends on relative transparency of master. Documents on heavy paper, particularly sulphite grades, will not print satisfactorily.

2. *Reflex contact process.* Light passes through photo-sensitive film sheet and is reflected back from document to be copied. Reflected light creates image exposure on film. Film is then developed and used as a transparent master for making direct contact photoprint copies. This process can be used for reproducing copies of reports, charts, and schedules from assemblies of strip or visible-margin forms or for copying documents written on heavy paper or card stock.

12.5.2 Hectograph duplicating. 1. *Spirit process.* Copies are produced from master by pressing sheets which have been wet with special solvent against the reverse side of the master on which the (negative) image has been printed by means of special carbon paper. (See Fig. 6.29.) Static data may be preprinted on master set by letterpress; variable data is added by typewriter or pencil. The most satisfactory dye is purple in color; other colors are available. Special paper is required.

2. *Gelatin process.* Image is written on front face of master using a special pencil, typewriter ribbon, or carbon paper. Negative image is impregnated into gelatin sheet by contact with master. Copies are produced by pressing blank sheets against surface of gelatin



Courtesy of Charles R. Bruning Company, Inc.

FIG. **6.28** SCHEMATIC DIAGRAM OF A DIRECT PHOTO-PRINT COPYING PROCESS.

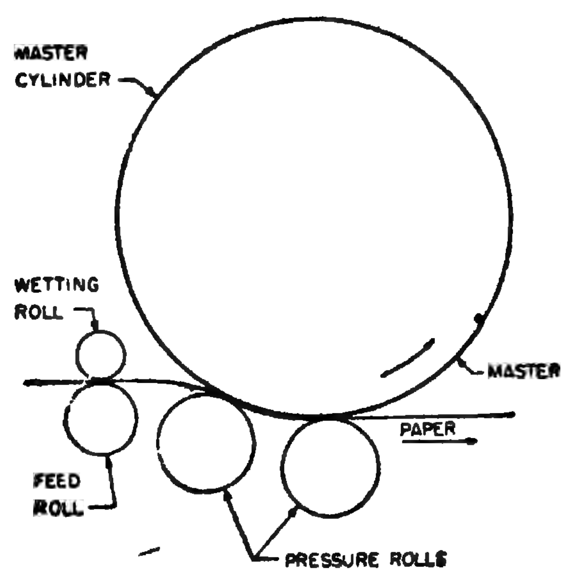
—a thin layer of gelatin, with impregnated image, is transferred to each sheet. Particularly suitable for reproducing reports larger than 8½ x 13 where relatively few copies are required.

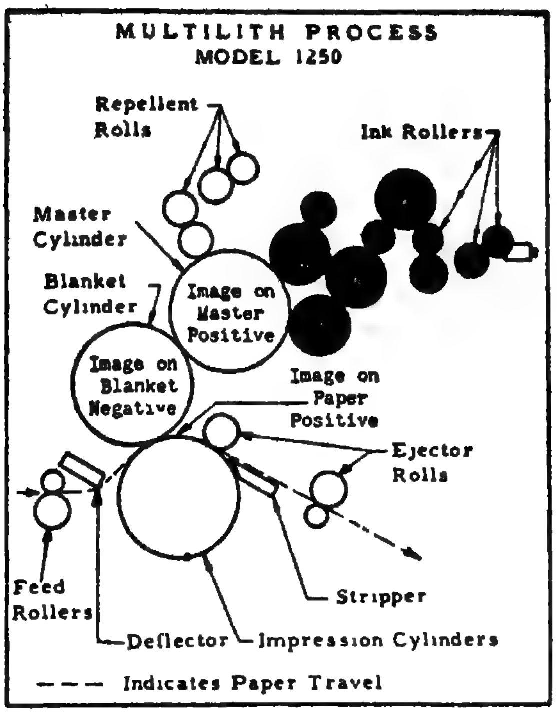
12.5.3 Offset duplicating. A simplified form of offset printing utilizing paper masters on which variable data may be entered with a special pencil, pen, typewriter ribbon, or carbon paper. Static data is preprinted on master. In duplicating copies, master is coated with ink-repelling fluid so that ink adheres only to image. Inked image on master (positive image) is transferred to "blanket roll" (negative image), and thence to paper (positive image). (See Fig. 6.30.)

12.5.4 Stencil duplicating. The basis of this process is transferring ink through a stencil master onto the paper. Stencils are made by typewriter or by hand with a stylus. Masters are made of wax-impregnated fibrous paper, thin-coated cloth, or plastic. Special absorbent paper is required. Equipment is available for general purpose office duplicating and for small-plate addressing and card duplicating.

12.5.5 Relief duplicating. The essential feature of this process is the use of

FIG. **6.29** SCHEMATIC DIAGRAM OF A SPIRIT HECTOGRAPH DUPLICATING PROCESS.





Courtesy of Addressograph-Multigraph Corporation.

FIG. 6.30 SCHEMATIC DIAGRAM OF AN OFFSET PRINT DUPLICATING PROCESS.

a metal plate on which the image has been embossed by machine. Copies are produced by pressure imprinting through inked ribbon or carbon paper. Primary application is in addressing and small card duplicating.

13. MATERIALS CONTROL SYSTEMS*

Management of materials inventories is a problem of administrative control. As such, materials control implies the rational determination of objectives, establishment of plans and standards, and comparison of actual performance with that which was intended. Implementation of materials control requires system—procedures, devices and people, policies and criteria, and organization.

* This article was written by Clark Henderson, Associate Operations Research Analyst, Stanford Research Institute, in cooperation with the author.

13.1 ECONOMY IN MATERIALS CONTROL SYSTEMS: THE OBJECTIVE

Materials economy, or the management of materials without waste, should be the primary objective in materials control systems. Comprehensive measures of economy probably cannot be stated in quantitative terms because of the difficulty of reducing the values of the services rendered by the system to money terms. However, the engineering economy point of view of increment costs and differences between alternatives is most helpful. It is therefore well, at the outset of a treatment of material control systems, to review some of the costs of material control and the lack thereof. It is emphasized that the *total* costs should be minimized. Ordinarily, this means that no single class of costs can be reduced to the ultimate limit without disproportionate increase elsewhere.

13.1.1 Costs of shortages. The failure to have correct materials at hand when needed will usually cause idleness, re-

scheduling, rerouting, substitution, overtime, delayed completion, or similar wasteful corrective measures. The frequency and duration of shortages is one of the major economic variables which a suitable system should control.

13.1.2 Inventory investment. Substantial inventory investments are generally necessary and economical; however, an increase beyond the optimum quantity will divert working capital from profitable uses and will increase insurance, property taxes, and losses through deterioration or obsolescence. The combined sacrifice of earnings and increase in costs is commonly as high as 15 per cent of inventory investment per year, and is often substantially greater.

13.1.3 Storage costs. The costs of storage, in a comprehensive use of the term, will depend upon the amount and kind of space used and the number and size of movements in and out of storage. Bulk storage of a limited variety of materials having infrequent receipts and issues will be relatively inexpensive. This tends to favor standardization and simplification to reduce the variety of items and to increase the size of average transactions, to centralize storage to allow for maximum space utilization, and to lower inventories. On the other hand, engineering and manufacturing requirements tend to limit the degree of simplification. Also, the need for prompt issues for known purposes tends to favor small issues from decentralized areas, and the advantages of large orders and less frequent procurement at quantity discounts and quantity freight rates tend to increase quantities on hand. It is clear that storage costs are sensitive to many economic factors and that the long-run effects of proposed changes upon storage costs may be difficult to trace. A detailed investigation of storage economy is especially appropriate when a storage saving or cost is used in comparing alternative methods of material control.

13.1.4 Clerical and administrative costs. Materials control systems have far-reaching clerical and administrative cost effects. Many treatments of this subject are confined almost entirely to describing simple means for reducing wages or salaries of personnel directly engaged in the system work. Although this is the most obvious measure of economy, it is a poor practice to proceed too directly or arbitrarily in efforts to cure problems of excessive cost by amputation. Merely reducing direct payments to personnel through the elimination of workers, or the use of less well qualified employees, may prove extremely expensive in time of salesmen, production control personnel, foremen, accountants, and purchasing people. This is true because a shortcoming in performance by the material control system may require costly corrective action by highly paid personnel in one or more of the other departments of the company.

One general alternative is to overhaul the present methods and procedures. Although this may involve a sizable original cost, continuing annual outlays for equipment and supplies, and perhaps even an increase in clerical and administrative labor, it is frequently possible to gain worthwhile improvements in all other important aspects.

13.2 MATERIALS CONTROL DEVELOPMENT AND ORGANIZATION

For effective materials control, the following things are required:

1. Standardization and specification of materials.
2. Development of classifications and symbols.
3. Specialization of facilities and equipment.
4. Specialization of personnel for records keeping, receipt, custody, issue, returns, and planning.
5. Development of media for recording and transmitting information.
6. Development of procedures for communication and coordination, particularly between materials control and engineering, production control, purchasing, receiving, inspection, and the cost and inventory functions.

7. Development of management standards and budgets.

The management problems inherent in establishing and maintaining the above dictate a centralization of authority and responsibility in a department, division, or section of the industrial concern. The location of this unit in the organization varies greatly between businesses. In manufacturing concerns which make assembled products, materials control can ordinarily be part of a strong production planning and control unit separate from purchasing, receiving, storage, and accounting. It is usually good practice to separate the organization units concerned with physical custody of materials from those concerned with record keeping and to divide the record keeping functions to provide internal checks and to fix responsibilities. The problems of protecting the concern against dishonest or careless conduct must, of course, be given a high priority where valuable items of common utility are involved.

13.3 MATERIALS CONTROL IMPLIES PROCESSING INFORMATION

Systems are developed for physical and quantitative control over materials, but the system itself deals exclusively with *information about materials*. This information about materials must be generated, reduced to usable form, recorded, transmitted, manipulated, and stored. This point is emphasized because of the rapid progress of electronics engineering in the development of high-speed information processing machines. It is clear that one of the important industrial uses of this equipment will be in materials control systems. Progress in this direction will lessen current emphasis upon the importance of manual devices and forms for materials control, because with such equipment, information is handled in coded form except at the input and output stages.

Neither conventional devices and forms nor electronic information processing equipment will *make* decisions or exercise judgment. The avenue of advancement in materials information processing, by whatever means, is in reducing the costs of *routine* clerical work and improving the accuracy, speed, quality, and completeness of information delivered to the decision maker.

13.4 INVENTORY STATUS AND CHANGE DATA

Any effort to control materials requires the accumulation of accurate information on the status of inventories and the processing of information about changes in status.

13.4.1 Simple records and methods for simple cases. One plan is to rely on the memory of an individual for past status and change data and to supplement this periodically by review of the physical stock. It is unfortunate that this method, suitable for very limited application, is so often used.

A somewhat better method is to use a simple bin tag on which all essential inventory and change data is kept at the point of storage. With close personnel attention, this method may prove economical. For example, in a department making small power distribution transformers, large amounts of special paper were used to separate the successive layers of copper wire. The paper was prepared within the department from large standard rolls. Withdrawals of prepared paper were made by the users. Bin tags showing additions to stock and, periodically, amounts on hand, provided sufficient information for planning the preparation of additional paper. When occasionally a shortage became imminent, preparation of a new supply could be started with but a short delay, and work rarely stopped. The only administrative cost was the periodic survey and count by the foreman's clerk.

One step beyond this is the two-bin or reserve stock method. In a typical application, a quantity of material corresponding to the order point amount is

packaged separately and placed in reserve. No cumulative record of inventory status and change is made. When the reserve stock package is opened, replenishment of the standard order quantity is begun. (For example, see Art. 10.3.5.)

All three of these schemes, as described, are deficient in their ability to provide planning or cost information. All are likely to produce serious errors when applied over a large range of materials or when usage or availability conditions are subject to abrupt changes.

13.4.2 Perpetual inventory records. The next stage of refinement of status and changed record keeping requires continuing records summarizing the information for each kind of material. In the simplest version, only receipts and issues are recorded, while the more complete versions will include the other data needed for predicting changeable quantity and time requirements. These records may or may not include cost information depending on the requirements of the accounting system.

Inventory records ordinarily are kept more or less remote from physical storage. This imposes a communications problem commonly solved by the use of forms. These forms typically serve the following purposes:

1. Forms transmitting data on the amounts and kinds of materials added to inventory. These will be receiving and inspection reports, materials returned reports, and documents from production control for material processed within the plant and returned to inventory. These reports also transfer responsibility for custody to the storekeeper.

2. Forms transmitting data on reductions in inventory. These will be material requisitions and documents authorizing the scrapping or sale of materials. These forms transfer responsibility for the material from the storekeeper to another person authorized to order withdrawals. The kinds and amounts of material are listed with the end use for which the material is released. A copy of this form ordinarily serves accounting requirements also.

3. Forms authorizing allocation of materials. This form may be an advanced copy of the issue document prepared by production control personnel when the production schedule is established.

4. Forms initiating procurement—ordinarily called purchase requisitions. By this means the purchasing agent is authorized to obtain stated quantities of particular kinds of material and he may also be advised of the degree of urgency for procurement.

5. Forms originated by purchasing, indicating the status of the vendor's compliance with the order.

The design of forms and the routing and distribution of copies are so closely related to the particular problems of a manufacturing concern and to the other systems in use that no special treatment is given them at this point.

13.5 PREDICTING MATERIALS REQUIREMENTS

Two general approaches to predicting future requirements are used. One of these is based upon the assumption that "history will repeat itself." The other assumes that end uses of materials can be predicted insofar as amounts and dates are concerned and that these data can be related to inventory levels and other requirements to develop procurement schedules.

Of these two approaches, the former is, of course, more easily applied, since no information other than current inventory levels and past issues is required for generating purchase requisitions (or production orders). However, unless its inherent limitations are recognized, it can yield quite unsatisfactory results.

13.5.1 The maximum-minimum inventory control method. A widely used technique of materials control is the so-called "maximum-minimum" method, whereby a predetermined quantity is requisitioned automatically each time the balance on hand (or balance avail-

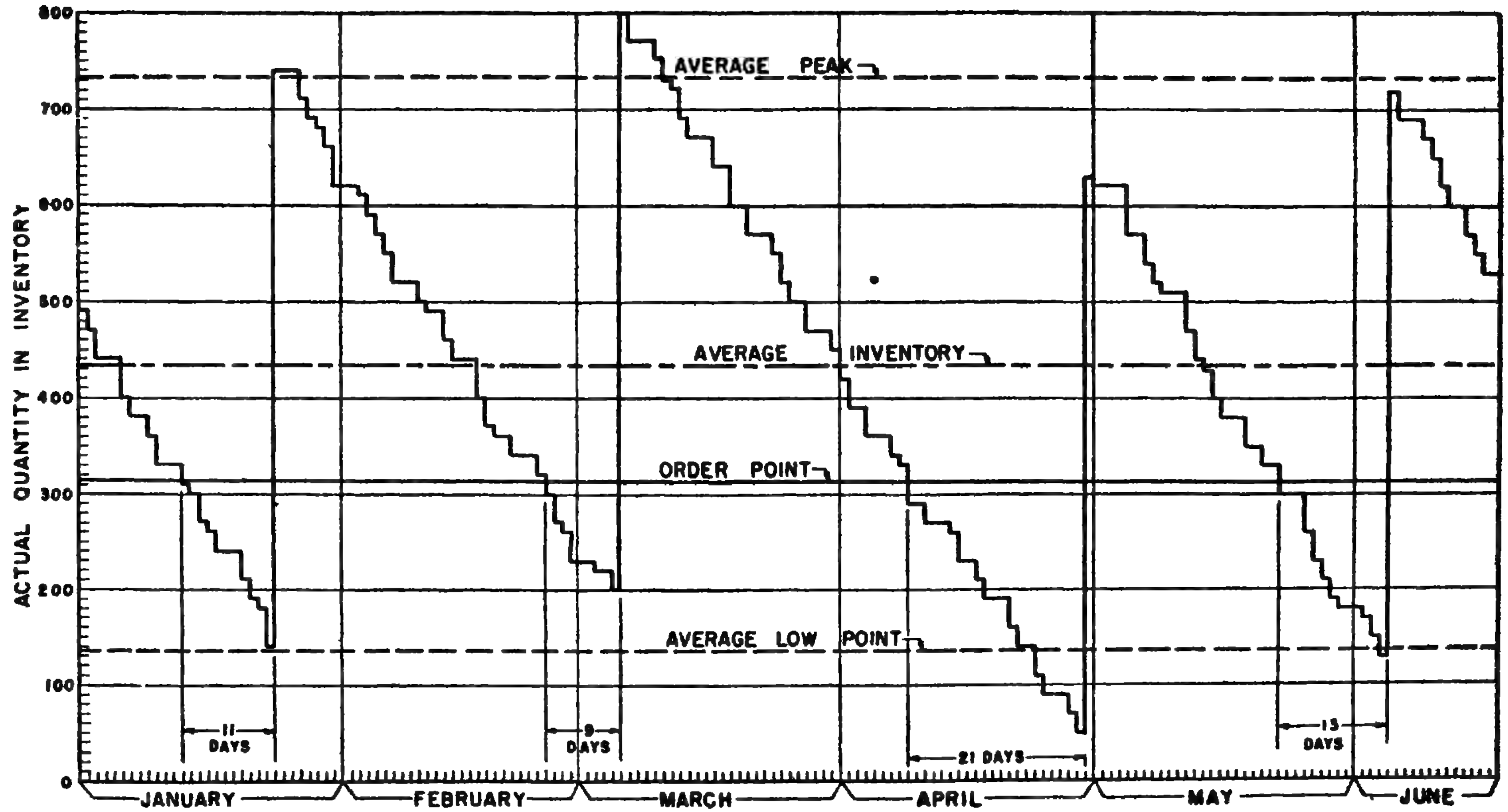


FIG **6.31** DIAGRAM OF THE OPERATING CHARACTERISTICS OF A MAXIMUM-MINIMUM INVENTORY CONTROL PLAN AS APPLIED TO AN INVENTORY ITEM FOR WHICH THE USAGE RATE IS STABLE.

able) has declined to the "order point." For this purpose, a continuous record is kept of receipts and issues (or receipts and allocations to known orders), showing quantities, dates, and the balance on hand (or available). Standard values are established for order points and order quantities.

The operating results of this method, for an inventory item which is relatively stable with respect to usage rate and procurement time, are diagrammed in Fig. 6.31. In this example, the order point has been established at 315 units. The procurement time varies from 7 days to 21 days and averages 12½ days (1.8 weeks). The average usage rate is 100 units per week. Therefore, the average low inventory point is $315 - 180 = 135$ units, although the actual low point may vary from about 215 units to as few as 15 units, or perhaps zero in extreme cases. The order quantity has been fixed at 600 units. Therefore, the average inventory is about $135 + 600/2 = 435$ units, and the average peak inventory is about 735 units, but may be as much as 815 at times.

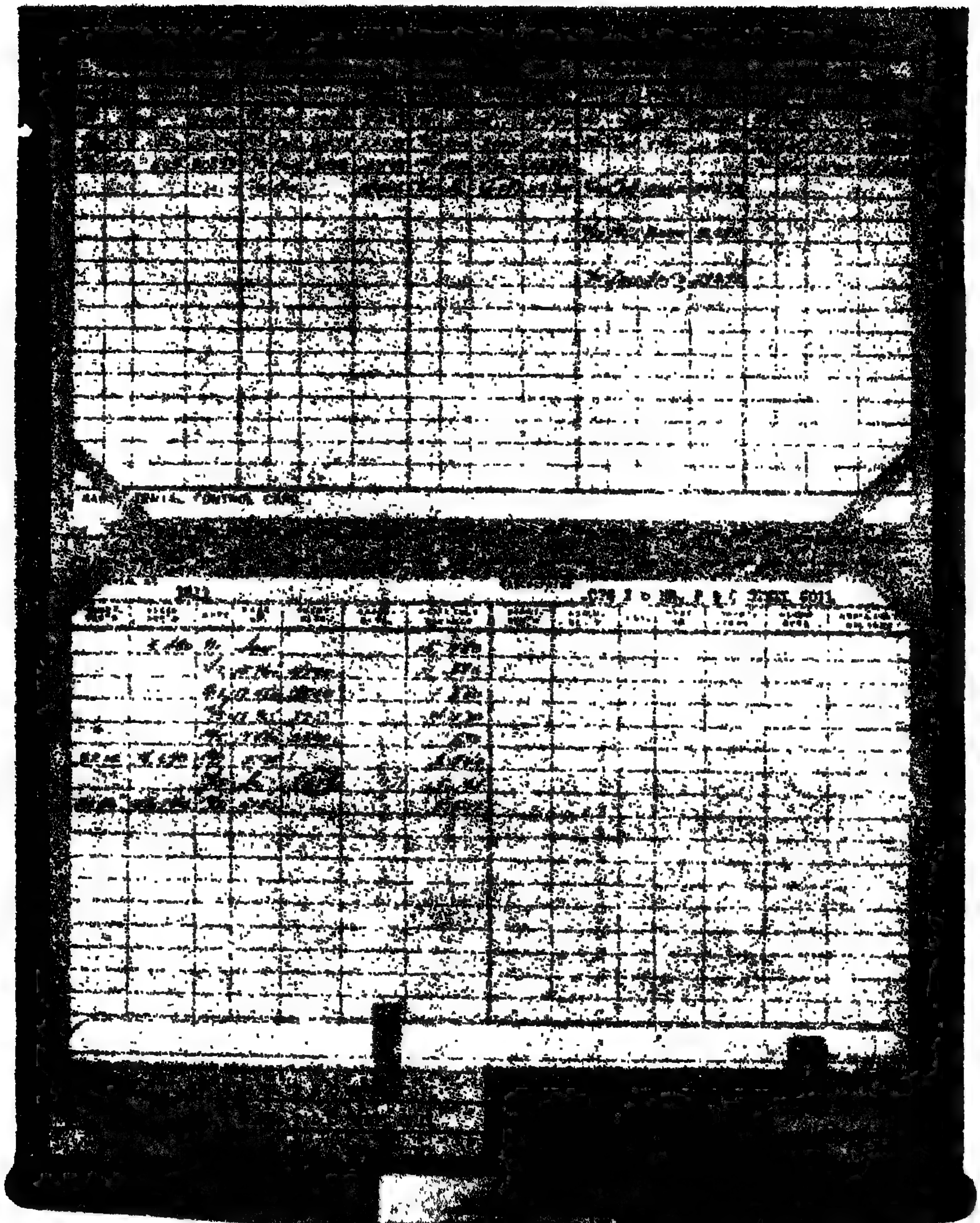
For an item under this type of control, the order point is ordinarily established by multiplying the average usage rate by the average procurement time, and adding a "cushion" (the so-called "minimum quantity"). This reserve or minimum quantity should be large enough to cover an unusually high usage rate or a delay in delivery. This amounts to setting the order point at a level high enough to allow for delays in procurement and high issue rates without developing a shortage.

The order quantity should be determined after the costs of storage and inventory investment, and the per-order costs of procurement have been considered (see Art. 13.7). Frequently it should be modified in accordance with commercial practices regarding packaging and shipping quantities and quantity discounts. The order quantity will depend, of course, on the usage rate, which ordinarily is based on past average.

Clearly, this method is capable of leading to serious shortages or surpluses for the simple reason that history does not necessarily repeat itself. If there are significant changes in usage rate and/or procurement time, the order point and order quantities, which are determined from historical data, will no longer be appropriate. Thus a trend, seasonal fluctuation, or sudden change in usage rate should be reflected by a change in both the order quantity and order point. Also, a change in average procurement time and/or maximum procurement time, due perhaps to a change in supplier (or production method) or a shift in market conditions, should be reflected by a change in the order point. Therefore, if this method of control is applied to other than very stable items, the standard order points and order quantities must be reviewed periodically in the light of recent changes and predictable trends. If seasonal variations are significant, what is needed in place of single values for order point and order quantity is either a variable set of values or a procedure for systematic recalculation using current or predicted data.

Also, because the method and the data may appear to be unassailable, there is a tendency to avoid questioning the results of a maximum-minimum inventory system, even when mistakes are made. There is a classical case of this from a military installation. A storage officer with an acute space problem finally succeeded in transferring the entire inventory of a dead stock item, 5,000 units, to a storage depot. The inventory control record, through a slight error, reflected this transaction as a normal issue. At this point, the replenishment system took relentless control, invoking special rules for zero-balance emergencies. The usage rate was recomputed as 5,000 units per month, and an urgent order was placed to cover the standard minimum inventory requirement (four months' supply) plus the standard order quantity (six months' supply). The order was duly expedited and 50,000 units were soon received.

In spite of its limitations, the



Courtesy of Remington Rand, Inc.

FIG. 6.32 AN EXAMPLE OF A DATA ACCUMULATION CARD RECORD FOR A MULTIPLE-USE INVENTORY ITEM.

maximum-minimum inventory control method is popular because of its simplicity and relatively low cost of operation. Some of the situations in which it is appropriate are as follows:

1. For items whose usage is stable for known reasons, as in the case of common supplies.

2. For items of small value and size, which therefore can be ordered infrequently in relatively large quantities.

3. For materials for which the timing

and quantities of future issues cannot be predicted accurately, but which must be available at all times.

13.5.2 Detailed planning of requirements. The second approach to predicting requirements and generating requisitions involves detailed planning of future needs. This method requires master schedules of the production for a future period, bills of material for each product, production schedules for each part, and a data-accumulating record for each item of material. (See Fig. 6.32 for example.)

As production is planned, the necessary material is allocated or reserved. The amount of material required, the expected date of issue, and the job number will be recorded on the data card. The card also will provide a record of the amounts on order, received, available, or uncommitted, and perhaps the amounts issued and physically on hand. All entries are dated and referenced to source documents. By projecting the detailed record into the future for a period greater than the time required for procurement, purchases can be closely regulated in accordance with planned consumption, and inventory levels can be held low.

For system economy, this method is necessary when single items are used for numerous products which are manufactured in job lots. The same approach, with simplified paperwork, should be used when material is acquired for a unique purpose, as when 20 instruments are purchased for use on an order of 20 special machines or when 22 forged blanks are purchased to make 20 gears for the same special order. In a different setting, this approach is also appropriate for materials used in standardized production of a complex product, such as refrigerators or automobiles, when the deliveries can be controlled to match consumption closely. Also, it is the only satisfactory plan of attack for many continuous production situations, such as in the food and basic materials industries, particularly where seasonal factors are important.

13.6 CRITERIA FOR MATERIALS CONTROL DECISIONS

It is probably impossible to establish a set of absolute criteria, or standards of performance, in a complex management problem such as materials control for which the general requirement is economy or management without waste. The criteria must ordinarily be relative. This is to say that one cannot ordinarily state that X dollars in inventory investment, Y square feet of storage space, and Z administrative dollars per year, together with intelligent management, will provide least cost operations. On the contrary, it is necessary to state two (or more) propositions which may be compared and evaluated according to the differences between them. Thus a proposed reduction in inventory levels would reduce investment, insurance, taxes, and perhaps other costs, but might cause shortages to occur more frequently, small quantities to be procured at higher costs, and other adverse effects. Having made the comparison between a continuation of existing levels and a reduction, a decision would be made, presumably, for the alternative which seems most economical. It would not, however, be appropriate to conclude that the best of all possible solutions had been made.

13.6.1 Use of formulas for determining order quantities. Much has been written on the determination of economic lot sizes, and many formulas have been developed for the purpose of determining the optimum lot size for purchase or production (see Section 3). In general, these formulas assume that one group of costs, including interest, insurance, taxes, and storage, increase directly with the average or total inventory level and that the average or total inventory level is determined by the lot size for purchased items and by the lot size, production rate, and consumption rate for manufactured items. When the sum of these inventory costs versus lot size is plotted, a straight line with positive slope is obtained.

The second group of costs is proportional to the number of times a lot is procured or produced and is therefore inversely proportional to the lot size. When this cost is plotted against lot size, a declining hyperbolic curve is obtained. The total of these two groups of costs may be expressed as follows:

$$Y = aX + b/X$$

where Y is the annual cost in dollars per year, a is proportional to the unit inventory carrying cost per year and b is proportional to the procurement costs per lot. Lot size is represented by X. Obviously, this total cost curve has a minimum value for some value of X. This is the value of X for which the first differential of the above equation is zero.

$$dy/dx = a - b/X^2 = 0$$

$$X = \sqrt{a/b}$$

As a practical matter, in most cases X may depart a sizable amount from this minimizing value without seriously affecting the total cost.

The use of economic lot size formulas of this type will, in some cases, be limited in application because of variables not readily taken into account in the formulas. For example, the formula assumes uniform usage during the consumption of a lot, which may or may not be a good assumption. The formula also implies that unit prices are constant without regard for quantity purchased or produced, whereas there may be distinct economies in large lot production or quantity discounts. Furthermore, prospective price changes must be evaluated aside from the formula results. Whitin* treats problems of economic lot size under less rigid assumptions. However, his formulas are perhaps too intricate for ordinary use.

13.6.2 Use of turnover rates as a standard of performance. It is common practice to relate inventory investment levels to total sales or cost of goods sold as a percentage or to compute the number of inventory turnovers per year by dividing average inventory into total usage.

Although this is a convenient practice for judging the results of inventory management, it may lead to serious errors if applied for inventory planning because of cyclical or seasonal fluctuations in volume and/or price. For example, if inventories are 50 per cent of annual sales in a period of intense activity, the ratio may increase abruptly due to a drop in sales with no change in inventory planning practices. By the same token, inventories at 50 per cent of sales in a relatively inactive period may be inadequate for a sharp increase in business. In either case, the concern will suffer losses of various kinds. This can be avoided, to a degree, by recognizing that turnover rates and inventory levels as a percentage of sales should not be constant at all volumes of sales.

For example, if $300,000 in inventory is adequate for $600,000 sales, it may well be that inventory should change only 1 per cent for each 2½ per cent change in sales. In that case, a constant percentage would lead to poor balance. It would be appropriate to establish the standard as a simple linear function of sales applicable between explicit limits. For example, in the case cited above, average inventory might be computed as follows:

$$Y = a + bX$$
$$Y = 180{,}000 + .20X$$

where Y is the inventory level and X is the volume of sales.

This would lead one to establish a $200,000 inventory level for $100,000 in sales (200 per cent), and $380,000 for $1,000,000 in sales (38 per cent), rather than $50,000 and $500,000 respectively. Clearly, the losses resulting from price and volume changes would then be less acute throughout a business cycle. It also seems probable that this plan would

* See Thomson M. Whitin, *Theory of Inventory Management* (Princeton: Princeton University Press, 1953).

better fit with normal production requirements.

Clearly, turnover rates cannot be used in planning materials inventories except as an over-all guide or as a convenient way to state general policy. For individual items, the average inventory should be established by making separate decisions about order point and order quantity, with proper consideration of over-all objectives, such as might be expressed as ratio or percentage standards of performance and of maximum space or dollar limitations.

13.7 EVALUATION OF SYSTEM PERFORMANCE

The evaluation of actual performance of a materials control system by comparison of results with plans may be accomplished through a budgetary control system insofar as inventory levels and administrative costs are concerned. Internal auditing procedures are required for the evaluation of detailed performances on shortages, excess inventories by items, and procurement penalties. Periodic or continuous physical inventory and reconciliation are, of course, checks upon the accuracy of records and losses of materials.

14. PRODUCTION CONTROL SYSTEMS*

14.1 OBJECTIVES OF THE PRODUCTION CONTROL FUNCTION

Planning a production program and controlling the actual performance relative to the plan are essential functions in any manufacturing organization. The necessity for such functions arises from the fact that the organization can continue to operate at a profit only if it is able to supply the required amount and quality of the desired items at the proper time and at a cost that will provide a satisfactory profit margin below the sales price. This requires adequate planning of all of the activities associated with production, coupled with follow-up to assure performance according to the plan.

Some planning and control are necessary in all manufacturing concerns regardless of how inefficient the methods of planning may be. However, it has been determined through years of experience that if the planning and control are done by specialists as a service function, rather than by operating personnel, they are usually more effective and are accomplished more efficiently.

Specific objectives of the production planning and control function usually include:

1. Maintenance of uniform work loads as far as possible.
2. Advance provisions for material and tool supply to prevent delays and idle time.
3. Preventing duplication of clerical and administrative effort when the same products are again produced.
4. Inventories which are adequate to meet demand but not excessive.
5. Minimizing setup and change-over time.
6. Centralized planning, constantly informed of load conditions, that can determine the best plan of action considering all the work to be performed and the commitments.
7. Information that will enable the planning group to anticipate difficulties resulting from breakdowns, materials delays, and other causes.
8. Accurate current information regarding the progress of all orders and provision for initiating corrective action with respect to delays.
9. Accumulating information that will improve the accuracy of future planning and reduce the work involved.

It can readily be seen that such an impressive list of objectives can only be accomplished satisfactorily through the use of a carefully organized system which is adequate in scope, reliable, and efficient. The production planning and

* This article was written by William G Ireson in cooperation with the author.

control function in a manufacturing company represents a specialized area of administrative activity which is subject to all the principles of systems and procedures design that preceded this article. From this point on, the subject will be treated as a special problem of system and procedure design, installation, and administration.

14.2 RELATIONSHIPS OF PRODUCTION CONTROL TO OTHER FUNCTIONS

As a system dealing primarily with the conversion of raw materials into package product ready for shipment, the production planning and control function must of necessity be closely related to and coordinated with many other functions within the organization. In order to carry out its objectives, it must receive information from a number of sources, employ that information properly, and, in turn, supply accurate useful information to other functional groups. In a large company, the market research department furnishes the detailed breakdowns of consumer reaction to products and the anticipated sales volumes by lines of product over a long future period. The sales department obtains and processes the actual orders for products, delivery dates, and priorities and transmits this information to the materials control and production control functions. This information becomes the basis for specific production plans which will support the company policies regarding inventories, economic lot sizes, delivery time, and employment. Engineering supplies the technical data for the products in the form of blueprints, bills of materials, tool and machine designs, materials specifications, and quality standards. Production planning translates this information into production orders for the fabrication of component parts and materials and the assembly or production of finished goods that will meet the specifications. Materials control maintains and supplies information concerning the availability of raw materials and purchased parts which is necessary for production planning. Materials control or production control must initiate action in the purchasing function to acquire the necessary materials at the desired time.

Production planning and control, then, is responsible for formulating a complete and workable plan that will provide the required output and coordinate the activities of various other departments. This plan must include the determination of the operations or steps through which each part or material will go, their sequence, the machines and tools to be used, and the time at which these operations will be performed. These activities are commonly known as product analysis, routing, and scheduling. Specific information concerning methods of production is ordinarily obtained from the methods or tool engineering department, and standards of time for their performance are from the time study or standards department, where these exist as separate departmental functions.

In turn, the production control department supplies information to most of the departments mentioned above. Information regarding possible shipping dates, delays, and progress on orders is transmitted to sales. Knowledge resulting from the planning and performance of production operations that is important to the engineering, methods, standards, purchasing, and production departments for future use is transmitted either formally or informally.

Thus it is clear that the effectiveness of the production planning and control function is largely dependent on the procedures by which information flows into and out of the department. These procedures must be positive, reliable, simple to operate, and require a minimum of clerical expense considering the company as a whole.

14.3 SYSTEMS MUST BE COMPATIBLE

It has been shown that the effectiveness of the production planning and control work is dependent on a great amount of information coming

from and going to other departments, but it must be remembered that most of this information is also used for other purposes by the supplying or receiving departments. The preparation of special reports containing only that information needed by production planning may be an expensive duplication of work. In turn, the production planning group may have to transcribe incoming and outgoing information from various documents and records to others. Thus, the production planning and control procedures must be subject to the organization's administrative system controls so that these procedures will be compatible with those of other systems. Only by careful analysis and design can the number of forms, copies, the amount of writing, and the time spent in the purely mechanical aspects be minimized. It is also important to analyze the system to be sure that all the conditions and situations are covered without an undue number of "special" or "exceptional" forms, reports, or improvised procedures. It is essential that the system be as complete and automatic as is reasonably possible, in order to reduce the amount of highly skilled supervision necessary to direct the work of the department. This is especially true with regard to the control procedures whereby deviations from the plan should be brought to light immediately and corrective action initiated. For example, machine breakdowns must be reported promptly by the system so that future work assigned that equipment can be rerouted before other production facilities become idle for lack of work. At the same time, steps aimed at getting the machine back into production must be initiated, the work must be rescheduled in accordance with the effects of the breakdown, and the sales and shipping departments advised of the expected completion delays if any. The system must be so designed to assure that such actions will be initiated when necessary with a minimum of delay and confusion. (See Arts. 6 and 7.) Thus, the production control system must interlock with those systems of the maintenance and the sales departments as well as those of the manufacturing and service divisions of the organization.

14.4 EFFECTS OF THE TYPE OF INDUSTRY ON PRODUCTION CONTROL SYSTEMS

It is impossible to devise a single, intelligent production control system as an illustration because every company has problems of production planning and control that are unique to that company.* On the other hand, certain generalities can be offered regarding the effects of the type of industry on the design of a satisfactory system.

"Industry" has been classified in a number of ways, but the same classification employed in Section 8, Art. 1 will be used here, and with the same definitions. "Continuous industry" will be used for those concerns that must, by the nature of the processes, operate 24 hours a day and 7 days a week, and in which an unscheduled interruption will result in loss of materials in process and/or damage to equipment. "Interruptible" will be used to designate all other types of industry, whether job shop, intermittent, or mass production.

14.4.1 Continuous industries. In many respects, the production planning and control system for a continuous industry is designed as the plant is designed. In most instances, the route of the material from raw state to finished product is fixed or at least there are a relatively small number of alternative routes. The timing of the addition of materials to the process is usually established by the capacity of the limiting unit of equipment. Standards of output in terms of both volume and quality are established, and automatic reporting and recording equipment is frequently installed right in the processing line so that deviations are automatically re-

* William E. Ritchie, *Production and Inventory Control* (New York: The Ronald Press Company, 1951), particularly Chapters 1 and 7.

ported and recorded. Even costs, in terms of labor, materials, and supplies may be standardized in advance of production.

Under these conditions, the production planning and control function usually consists of relatively simple procedures that assure an adequate supply of materials, establish the "mix" * of the product by periods of time, such as months or quarters, and maintain records of production. This situation is the result of the fact that the production planning and control group have a relatively small number of possible decisions to make, while the corresponding group in an interruptible industry is faced with a very large number of possible decisions.† The production order release in the continuous industry usually consists of a statement of the quantities or mix of the product for a given period without the necessity of specifying the route or the schedule. The production order release can often be prepared well in advance of the production period, and all departments concerned can be advised of any adjustments that may be necessary, such as an increase or decrease of the labor force.

14.4.2 Interruptible industries. The interruptible type of industry includes a great variety of manufacturing conditions. The most severe condition is that where each product is custom-made with little or no prospect of being made again. The other extreme is that where a small number of standardized products are made constantly by mass-production methods and in very large quantities. Between these two extremes lie a large number of variations, each providing special problems for the production planning and control function. Most manufacturing concerns of the interruptible type at some time encounter a wide variety of these conditions. The planning and control system then must be designed with changing conditions in mind and with such flexibility that it can be used in a period of special requirements without major changes. It is, however, important to review the manufacturing conditions from time to time to see that the system has not become obsolete or inadequate as a result of changes in volumes, designs, and lines of product. It is clear that the design of such a system is more difficult and requires more careful analysis than that of a continuous industry or of a single-product firm.

In any event, it is important during the development of a system to establish the relationships with other departments, the specific objectives of the system, and the criteria that will be used to measure the effectiveness of the system (see Art. 3). These matters must be determined in light of the conditions of the specific company and its general organizational structure. The differences that regularly occur among companies in the allocation of duties, responsibilities, and authority necessitate that the systems be designed specifically for the concern in question. Generalizations regarding relationships, objectives, and measures of effectiveness do little more than provide a guide for the systems analyst.

14.4.3 Types of production control systems. There are a number of basic types of production control systems in use at this time. They are referred to as:

1. Order control or job-lot control.
2. Flow control.
3. Block control.

The order or job-lot control method is commonly used in those concerns that manufacture a variety of items with each batch of the work representing one constantly-identifiable lot to which is assigned a number which becomes the basis for cost accumulation. One order may, because of its size, be broken up into a number of sub-lots for convenience in materials handling, work assignment, and shipment. This type of

* "Mix" refers to the proportion of each different product, or form of product, to the total output for the period.

† However, the production planning decisions required in a continuous industry are often more complex and more important in terms of dollars and/or company success, and may therefore warrant more elaborate analysis and executive review.

production control presents the greatest number of problems in coordinating the work of planning, control, sales, manufacturing, and shipping. This is the type described at length in the following articles.

The flow control method is most frequently used in continuous industries or in those companies that manufacture a standardized line of product more or less continuously without any reason for identifying one batch from any other. The control is based upon the concept of a fluid flowing past a number of points. Commonly, the control points correspond to departments or cost centers, and so much work is scheduled to be completed in each department or process in a given period of time, week, or month. In comparison with job-order control, discussed later, the planning function is largely eliminated in this method and what remains consists primarily of establishing weekly or monthly production authorizations (quantities). On the other hand, the control function becomes more important. The type of industry using this method usually manufactures to stock in anticipation of the receipt of orders.

The block method is similar in many respects to a combination of the two previously mentioned types. The "block" represents the amount of work that can be performed by a person or team of persons in a given period of time. The length of the time period may vary from a few minutes (as required in mail-order houses for gathering, checking, and wrapping mail orders), to a day or week (as required in some shipbuilding yards). All work to be done in the plant is divided into blocks and assigned to certain time blocks for performance. The material in each block is then expected to progress as a physical unit from one location to another and to move forward all at once at the end of each block of time. It is easily seen that it is possible to process any kind of order through a system of this kind. Any batch or job may be specifically identified all the way through the plant, or stock items may be processed with only one cost accounting charge number being used for a large number of blocks.

14.5 DIVISION OF DUTIES AND FUNCTIONS IN PRODUCTION PLANNING AND CONTROL

The duties and functions involved in production planning and control usually fall into four fairly well-defined divisions:

1. Forecasting and estimating.
2. Developing production plans.
3. Controlling activities.
4. Preparing reports and initiating corrective action.

14.5.1 Forecasting and estimating. Budgetary control as practiced in most concerns requires that a number of budgets, including the production, labor, materials, overhead, purchasing, and capital improvement budgets, be prepared well in advance of the period covered by the budget. The sales budgets and financial budgets are commonly made by the sales department and the executive division, but the other budgets listed above must be prepared by persons familiar with the manufacturing operations, technical details of the products, and the manufacturing capacities of the plant. The production planning and control department commonly is the one group most familiar with these matters because it is daily in contact with the manufacturing, engineering, materials control, and purchasing divisions. It therefore is logical that it should be called upon to convert the master budgets into specific budgets that represent attainable or workable plans. For this purpose, the department commonly maintains continuous records of work ahead, product designs, bills of materials, and productive time available and knows what effects varying the product mix and schedules will have on these budgets. The department will be called upon to provide estimates of many different kinds of factors and the effects of changes in product lines, volumes, materials and methods. These activities constitute an important part of the

department's work and a separate group of employees usually is permanently assigned to this work.

14.5.2 Developing production plans. Planning the production consists of formulating specific plans that establish what is to be produced, how it is to be produced, and when. Formerly, these items were decided by the foremen and workmen in the factory, but it was shown that this practice was no more logical than having the men make parts without complete dimensioned drawings and specifications. The foremen and workmen are skilled in operating factory equipment, not in calculating dimensions, planning detailed sequences of operations, determining the best combination of tools and equipment to produce a given part, nor in recording the results of this work, so that the same planning would not have to be done over again each time the part is made. Departmental foremen and workmen are usually familiar with only a small part of the plant and are unaware of the work load ahead in other departments. Their decisions would be made to optimize the work in only one department (their own) without regard for the effects of these decisions on other departments. For these, and many other obvious reasons, it has been proved that the greatest efficiency can be obtained by employing a group of persons highly skilled in dealing with these problems and by supplying the group with complete information from all departments regarding work loads, production capacity, tools and auxiliary equipment, delivery promises, sales forecasts, and a systematic means of storing and using all this information as the situation changes from day to day. Through these procedures, the over-all plant output can be maximized while minimizing work-in-process inventory, setup time, idle machines and workmen, and avoiding conflicts between departments.

In physical form, the production plan ordinarily consists of some combination of the following:

1. Route sheets: The sequence of operations in general terms.
2. Operation sheets: One for each operation on the route sheet. Specifies the details of how each operation is to be performed.
3. Work schedule: The assignment of time on a given machine (or production center) for each operation shown on the route sheet. Individual job schedule may be shown on the route sheet or on a separate form. Summary schedules by machine, production center, or department may also be required.
4. Orders: This group may be responsible for the preparation of written orders that will be used later in putting this plan into effect. These orders may include: production order (authority to produce), materials and parts requisitions, tool orders or requisitions, drawing or print requisitions, and move orders.

Working from blueprints and a bill of material, a route sheet is often prepared for each separate part that goes into the final product. The process of determining the steps and their sequence, the tools and machines to be used, and the material, is known as the product analysis, and requires a person who is completely familiar with the manufacturing procedures and equipment available in the factory.

If the route sheet is used as a production order, it will contain a heading, identifying the part, drawing number, production order number, master schedule information, order quantity and lot size, destination (stock or customer), and any other information that is necessary for the particular system in use. It then includes, usually in a column, some or all of the following information: operation number, operation description, machine identification, department, drawing number, tool numbers, standard time for the operation, set-up time, total time allowed for the job, time to start operation, time to finish operation, and time and quantity finished (actual). It is obvious that such a route sheet has been designed to combine a number of activities and eliminate the necessity of duplicating much of the information on separate forms. For instance, the route sheet may be a multi-copy form or

master (see Art. 11.3) which will be partly filled out by the product analyst, with machine and tooling information added by the tooling clerk, and the schedule added by the schedule clerk. Finally, as the operations are completed, the control group uses the "time finished" column as a means of recording the progress. One copy would be retained in the control office, one copy in the dispatcher's cage, one copy (a heavy one) would travel with the work, and other copies would be used by the foremen, accounting, and perhaps the shipping and sales departments.

Operation sheets are prepared only for those operations that are new or that are somewhat complicated and require detailed instructions. Ordinarily, the instruction sheet will not contain all the heading information contained in the heading of the route sheet, but will have columns for sub-operation numbers, sub-operation description, specific tool used, machine speed, feed, depth of cut (or corresponding type of information for other types of machines), and standard times. These operations may be described in terms of the elements used in establishing standard times by the time study department.

The schedule for the work is arranged by the schedule clerk on the basis of information about the availability of machines for new work. Usually, a scheduling load planning device of some kind (see Art. 12.2) is used to show graphically the work assigned to each machine, production center, or department. From this the clerk knows when equipment is free for additional work. He then works out the limiting dates at which each successive operation must be finished on all the parts so that the finished product may be shipped by the promised delivery date. At the same time, he is concerned with the problem of keeping the in-process work at a minimum, optimizing the use of machines, and holding the over-all time in process for each order as small as practicable. With the limiting dates known for each part, he begins with the last operation and works backwards. As he assigns machine time, he records it on the schedule sheet and also indicates on the planning device that the machine has been assigned for a specific period of time to that specific job. In many situations, a planning device of some kind is essential so that rapid and accurate changes can be made in the schedule to accommodate the unexpected interruptions that will always occur after a production sequence has been started.

Orders are necessary to authorize action as well as to transmit information and provide for control of materials, labor, machine time, and many other cost factors. Authorization to manufacture originates in the sales department of most companies. This authorization in the form of a sales order is translated by the production control department into authorizations to issue materials, start work, purchase parts and materials, allocate machine and labor time, and initiate engineering work. The transfer of this authority to the operating group requiring the authority is frequently implied by entering a production order in the factory, but it may be specifically transferred by requisitions to the materials control group for purchased items, by requisitions to the stores department for materials to be issued to workmen, and by labor time tickets prepared in advance bearing specific job numbers and operation numbers. Time can be saved by having many of these forms prepared by the production planning group at the time the job is planned. This is particularly true if duplicating methods are used so that most of these forms can be prepared from one master copy.

14.5.3 Controlling production activities. The old adage "Plan your work and work your plan," points up the fact that a plan is of little value unless it is followed. The planning group has been charged with the responsibility of preparing a set of workable plans for each item to be produced, but someone must be responsible for the follow-up to assure that the plans are followed. This, the control phase of production planning and control, centers around the dispatcher. The dispatcher is responsible for

putting the plan into effect and following it to detect immediately any variations and to instigate corrective action.

Typically, completed production plans are sent to the dispatcher who stores them in a systematic way so that he will know what work is ahead for every machine and can detect deviations from the plan as the work progresses. He may have a duplicate machine-work-load chart or schedule sheet which he keeps up-to-date as the production plans arrive. He is thus the link between the planning group and the producing group in the shop. Ordinarily, the dispatcher has no authority over the foremen. His responsibility in that connection is limited to informing the foremen of the work ahead and the schedule prepared by the planning group. If for any reason the work does not progress as planned, the dispatcher relays this information back to the planning group. The planning group makes proper adjustments in the schedules, informs sales of the delays, and notifies appropriate persons if corrective actions are needed.

Other duties carried out by the dispatcher usually consist of the preparatory work relative to initiating new work. He may be responsible for gathering together the drawings, operations sheets, tool orders, materials and parts requisitions, and time tickets and issuing them all at once to the first machine on the route sheet at the proper time. He may actually have the materials and tools collected on a truck or skid along with the papers and have it moved to the machine shortly before work is to be started.

The dispatcher also collects information on work progress and maintains a record showing the progress of the work so that he will know at any time whether work is behind, on, or ahead of schedule. At periodic intervals, he will make reports to the control center of work behind or ahead of schedule. Move tickets or labor time tickets commonly provide the dispatcher with the necessary information.

A common practice in some plants is to employ persons to trace work through the plant and to report on its progress. These persons are known as expediters or stock chasers. Too frequently, these expediters are used only to locate work that has been "lost" or is seriously behind schedule. Although one or more expediters may be required in a well-managed plant, it is more desirable for the production control system to be so designed that the status of all jobs is known at all times, and that difficulties will be anticipated before they become serious, without the need for expediters. Here, as in many other industrial activities, preventive measures are better than corrective measures.

14.5.4 Reports and corrective action. The results of the production planning and control function are of interest to two major groups: management and sales. Management is interested in knowing how effectively the function is being performed and the reasons for anything less than optimum utilization of production equipment. Some of the items of information management desires for control purposes are:

1. Summary of actual production by departments and/or products.
2. Orders not completed on time and reasons.
3. Lost time of machines and labor, by causes.
4. Productive capacity available for additional work by future periods.

The production control department is in possession of all of this information and is the logical source of these control reports.*

Continued good relations with customers demand prompt delivery of orders or at least fair warning of delays. Thus, the sales department may frequently need information regarding progress of orders which only the production control department can supply. The principle of management by exceptions is customarily applied here and the sales department assumes that deliveries will be made on time unless advised to the contrary by Production Control. All

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* See Art. 11.5 concerning the design of control reports.

too often, the sales department promises deliveries at specified times without consulting the production control department. It behooves Production Control to initiate a periodic reporting procedure that will inform the sales department of the prospective delivery time on future orders received. This will help to prevent delivery promises that cannot be kept. Also, Production Control should report back to Sales at the time of the receipt of the order if the promised date is too early to be met without delaying other orders.

The production control department is interested in improving its own performance and needs to maintain records of its work in order to evaluate and improve its methods. Records may show consistent errors due to use of poor standard data, unreliable estimates of scrap and other losses, or failure to make proper allowances for such things as move time, normal delays, instruction, and so forth. A greater accuracy in planning will result from the correction of practices based upon such information. Standard data may not be available and the scheduling may have to be done on the basis of past experience only. Careful analysis of actual time records and tabulation of the data by product classifications and quantities, type of machine and operation, and materials will provide for better estimates in the future. Systematic maintenance of route sheets, schedules, job progress reports, and other working papers, will prevent having to repeat the same work when the product is made again. Thus, the total work (and cost) of the production planning and control function can be reduced for a given volume of work as better information is accumulated.

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SECTION 7

Industrial Climatology

Ray K. Linsley

DEFINITIONS

Average—The arithmetic mean of a group of data. Commonly used in climatology to refer to the mean value of a weather element over a large area for a specified period.

Climate—The summation of weather at a given place over a long period of time.

Macro—A prefix combined with the words climate and variation to refer to the broad features of climate over an extensive area, such as a continent.

Mean—An arithmetic average of a group of data. Commonly used in climatology to refer to the average of a time series, such as the mean temperature for a day, month, or year.

Micro—A prefix combined with the words climate and variation to refer to the small-scale features of climate within

a limited area, such as the micro-variations of temperature within a city.

Normal—The arithmetic average of the values of a weather element for a specific day, month, season, or other portion of the year over a long period of years. Since no standard length of record has been adopted for determination of normals, the period should always be specified—for example, "50-year normal."

1. WEATHER AND MAN

Contrary to an oft-repeated saying, man has done a great deal about the weather. He has probably devoted more effort to combating weather than he has to any other purpose, with the possible exception of waging war. Perhaps man will eventually learn how to actually control the weather. He has already exerted some measure of weather control over small areas by fog dispersal over airports (FIDO), orchard protection by smoke and heaters, and small-scale modification of clouds by "cloud seeding." For the present, however, most of man's efforts against the weather can be summed up in two words—"protection" and "avoidance."

2. WEATHER PROBLEMS IN INDUSTRY

2.1 PROTECTION FROM THE WEATHER

Buildings are intended almost exclusively to afford protection from weather. Starting with a natural cave, man has developed the art of shelter to the point where he can create enormous skyscrapers with artificial weather provided by heating and air conditioning. Space does not permit a detailed survey of efforts to provide protection against the weather, but irrigation farming, clothing, instrument landing aids for aircraft, lighthouses, ultra-high frequency radio, the modern automobile, flood-control dams, and many other items may be cited as examples. Thus the concept of protection goes beyond mere physical shelter. It includes all devices designed to ward off the harmful effects of weather. The design of protective works must include consideration of physical resistance to water and wind, chemical resistance to radiation and air-borne compounds, and numerous other problems associated with modern materials engineering.

2.2 AVOIDANCE OF THE WEATHER

If the weather of the world were invariant—if every location had the same weather at all times—the planning of protection against the weather would be simple. Unfortunately, weather is highly variable. In the interests of economy, man tries to plan his activities in such a way that minimum protection is required. Moreover, man is not inclined to seek protection until the need for it is great. Thus, it becomes necessary to schedule production, distribution, and sales of protective materials at the times when they are needed. It is not uncommon to plan a production operation in such a way that it may be carried on outdoors. These are only a few of the ways in which man tries to offset weather influences by planning his activities to avoid the weather.

3. WEATHER FORECASTS

If a structure is to be designed against the weather, or if plans are to be made to avoid inclement weather for a specific operation, it is necessary to have some information concerning the weather to be expected. The ideal solution would be found in a detailed forecast of the weather for the times and places of interest. Highly successful utilization of special weather forecasts has been made in connection with frost warning for citrus and cranberry growers, rain warnings for fruit drying, light intensity forecasts for scheduling electric-power production, snow forecasts for highway and railroad snow-removal operations, and flood forecasts for emergency protection and evacuation opera-

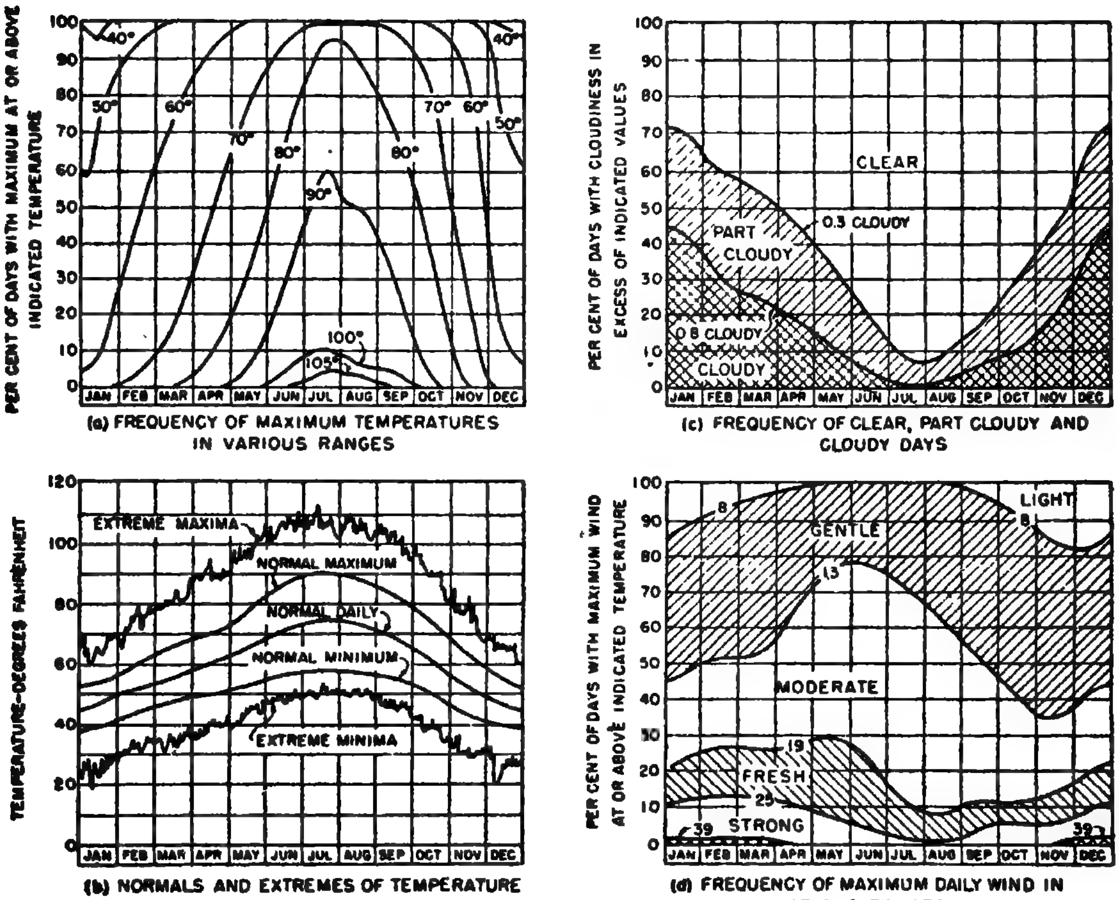
tions of all types. For the most part, such forecasts are limited to periods not exceeding about 48 hours in advance. Forecasts for longer periods become, of necessity, less specific as to the time of occurrence of weather phenomena and less accurate in the estimates of the magnitude of the weather event. The limit of practical forecasts at the present time is at about 30 days. Forecasts of this length indicate no more than that the average temperature and precipitation during the period will be near, above, or below normal.

Despite the limitations on range and accuracy of forecasts, an intelligent use of forecasts can provide many benefits to industry. Experience has shown that a trained meteorologist who devotes himself to forecasts for a specific purpose and who has a thorough understanding of the uses to which the forecast will be put can do a better job than one whose assignment is to prepare a general forecast for a large area. Consequently, the industrial meteorologist has taken his place on many industrial staffs, to aid in advance planning against the weather over short periods.

4. CLIMATOLOGY

The lasting qualities of paint, the design of an industrial plant, the advance manufacture of seasonal merchandise, and solar heating are examples of operational problems requiring information about weather to be expected over a period extending beyond the range of successful weather forecasts. What is needed is information on *climate*, the sta-

FIG. 7.1 EXAMPLES OF GRAPHICAL PRESENTATION OF CLIMATIC DATA FOR SACRAMENTO, CALIFORNIA (PERIOD 1877-1942).



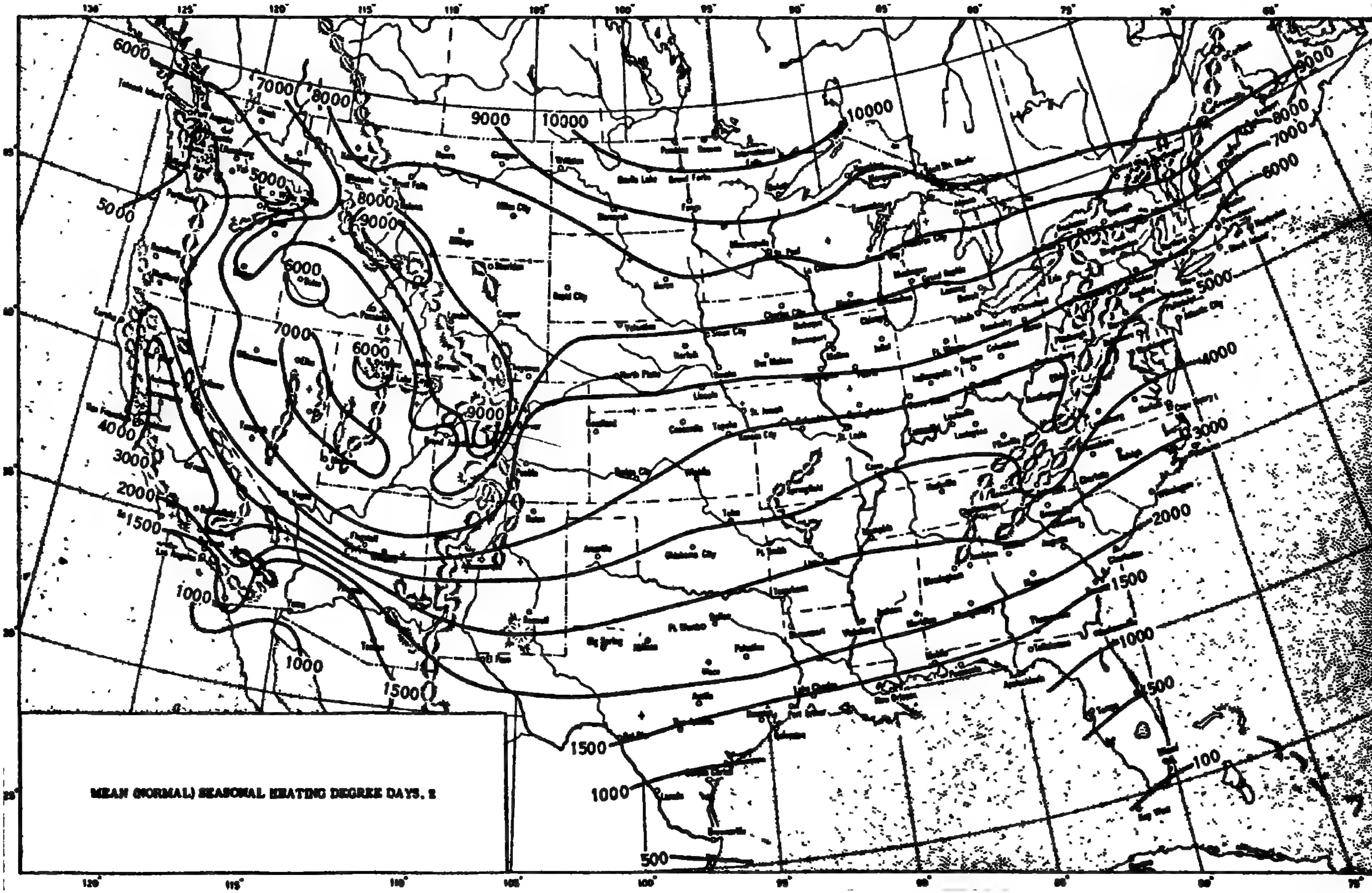
(a) FREQUENCY OF MAXIMUM TEMPERATURES IN VARIOUS RANGES

(c) FREQUENCY OF CLEAR, PART CLOUDY AND CLOUDY DAYS

(b) NORMALS AND EXTREMES OF TEMPERATURE

(d) FREQUENCY OF MAXIMUM DAILY WIND IN VARIOUS RANGES

From *Climate of Sacramento*, U. S. Weather Bureau Office, Sacramento.



MEAN (NORMAL) SEASONAL HEATING DEGREE DAYS, 2

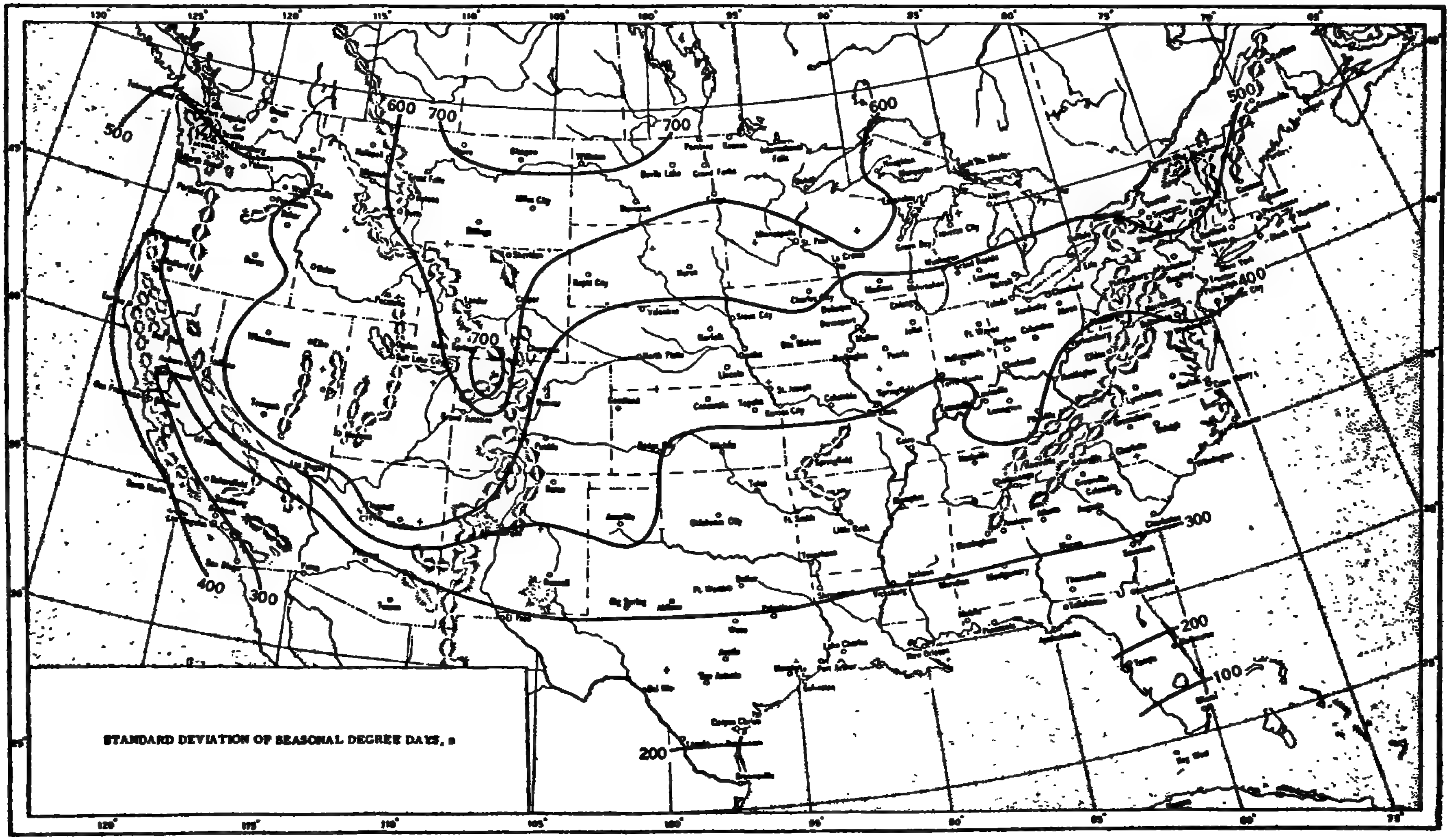


FIG. 7.2 NORMAL DEGREE DAYS IN THE UNITED STATES AND THEIR STANDARD DEVIATIONS (U. S. WEATHER BUREAU).

tistical collective of weather elements over a long period of time. The climatological forecast is quite different from the usual weather forecast. The climatologist assumes that the weather of the future will be like the weather of the past, and that statistical analysis of past weather records can provide a summary of the weather to be expected in the future. The climatological forecast may include a description of average weather, the possible range of values of a weather element, the probable number of times that a certain weather condition is likely to occur in a given period of time, or the probability that the weather of a given day, week, or month will be within a specified range of conditions. Climatology cannot predict the specific weather to be expected at a given place and time (unless its probability is 100 per cent), but only the probability or odds that certain weather conditions will occur. The climatological forecast provides the odds for a gamble on the part of the planner, or, in more elegant terms, the probabilities upon which he can base a calculated risk.

5. TYPICAL PROBLEMS IN CLIMATOLOGY

5.1 GENERAL

In the sections that follow, some examples of the application of climatology to industrial problems are presented. Most climatological problems involve numerous complications and their solutions require extensive analysis of data. Although the list of examples is far from comprehensive, it is hoped that the reader will be encouraged to develop solutions to the specific problems that he encounters. A discussion of the sources of climatological data, how to interpret them, and how to treat them statistically is presented in Arts. 6-15.

5.2 GENERAL INFORMATION

Certain weather problems are best solved by compiling general information in a form that can be easily used. This type of problem is encountered where an operating official must make decisions when the controlling criteria depend upon the specific circumstances of each case. The pertinent data are summarized in tabular or graphic form so that the desired information can be readily obtained. The best presentation for a particular case depends on the nature of the problem and on the personal preferences of the user. The *Climatic Handbook for Washington, D. C.** illustrates a general summary of data intended for a variety of users. The *Airway Meteorological Atlas for the U. S., Atlas of Climatic Charts for the Oceans,* and *Summer Weather Data* represent compilations of data covering a large area but intended primarily for a specific class of problems.

Illustrative charts showing probabilities for wind speed, temperature, and cloudiness for a single station are shown in Fig. 7.1. Charts of this type are desirable when the variations in probability throughout the year are important. Figure 7.2 utilizes a map of normal heating degree days (Art. 8.2) and a map of the standard deviation of this element to depict variations in probability over a large area. Other isopleth charts (maps showing lines of equal values of a variable) are shown in Figs. 7.12, 7.15, 7.17, 7.18, 7.19, and 7.20. Most such maps are suitable only for depicting the broad features of the climatic pattern. In the mountain regions, the small scale does not permit accurate representation of the variations in the element being pictured. A table of the data for the key stations used in plotting the map would be a more realistic presentation. Several other types of graphical presentation appear in Figs. 7.4, 7.6, 7.7, 7.8, 7.14, and 7.21. In each case, the data could be presented in several other pictorial or tabular forms.

5.3 SITE SELECTION

Climate is rarely the only factor that governs the selection of a site for an industrial plant, but it is often

* See bibliography at the end of this section.

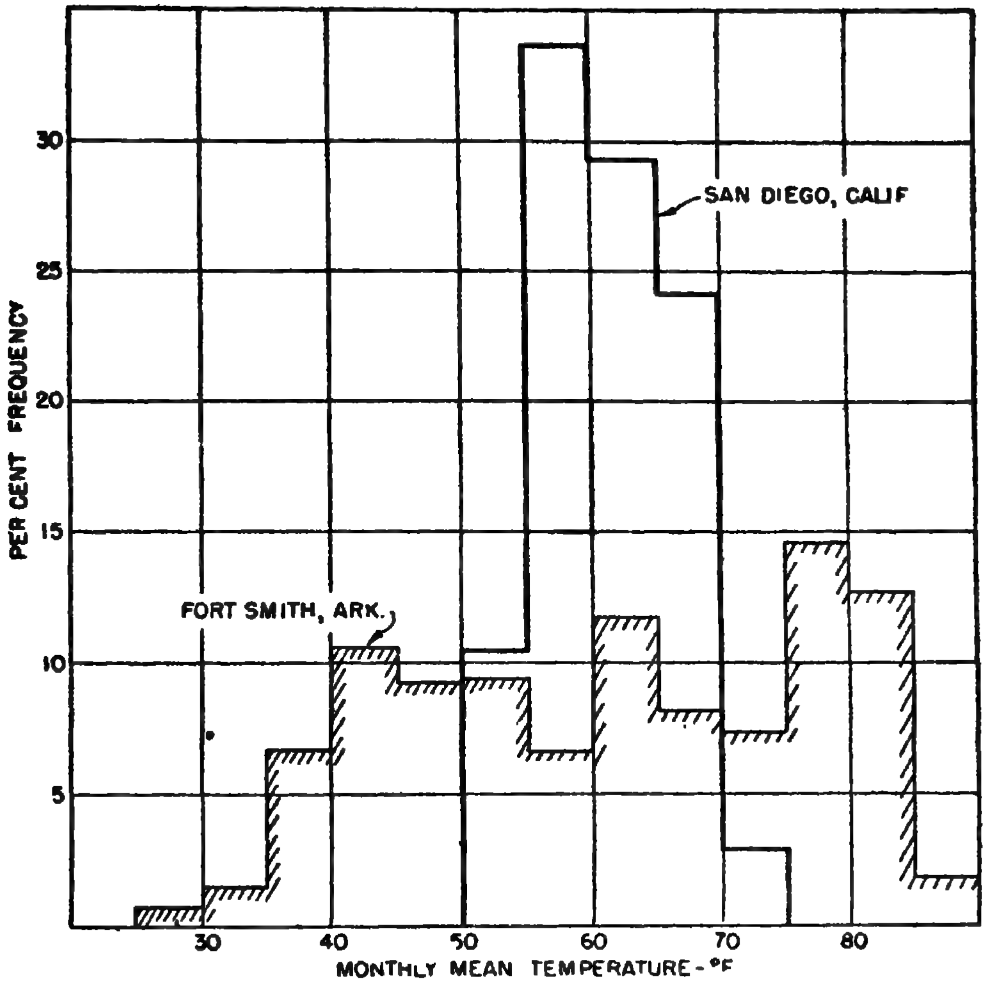


FIG. 7.3 COMPARISON OF TEMPERATURE FREQUENCY DISTRIBUTIONS FOR TWO CITIES WITH THE SAME NORMAL ANNUAL TEMPERATURE.

quite important. Assume that an industry desires a site for a plant requiring constant temperature at 60° F. No location will afford such an ideal situation naturally, but a site that has a mean temperature of 60° and a minimum standard deviation of temperature will require the least amount of artificial heating and cooling. The climatic factor must be weighed with other economic aspects in the selection of a suitable site. Figure 7.3 shows the frequency distributions of mean monthly temperature for two cities having mean annual temperatures very close to 60° F as selected from Fig. 7.12. San Diego is clearly the preferable site. The example demonstrates how important it is to consider the frequency distribution of the weather element in question as well as its normal or average value. Note that if the distributions of Fig. 7.3 had been computed from daily temperature values, the differences between the two stations might have been more marked. Monthly or annual averages tend to suppress the extreme variations.

5.4 SITE LAYOUT

After an industrial site has been selected, weather factors may continue to be important in determining the plant layout. Assume a plant including an outdoor operation that should be located upwind of a plant unit that will produce considerable dust. In addition, the outdoor work area should be protected from wind for the comfort of the

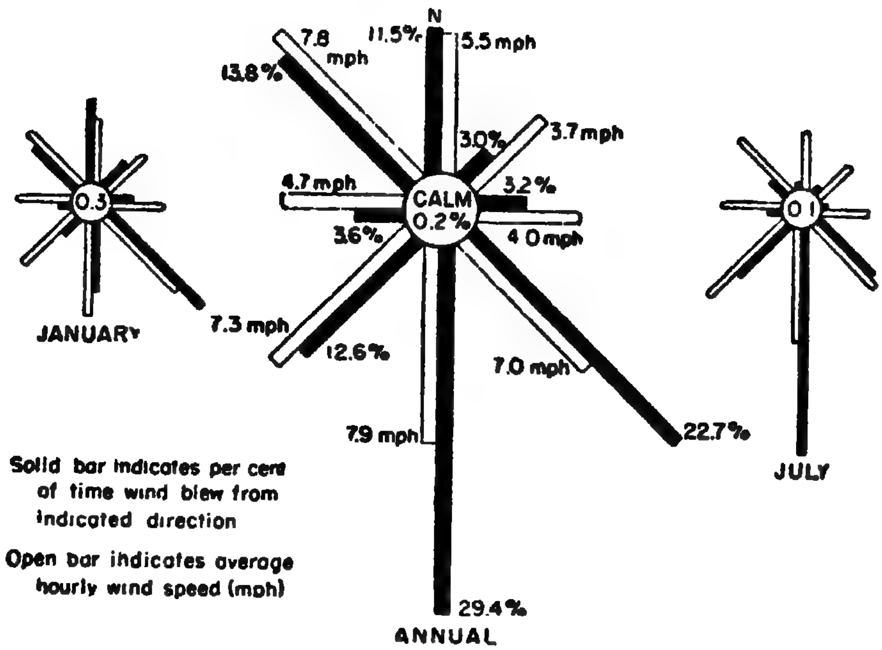


FIG. 7.4 WIND ROSES FOR SACRAMENTO, CALIFORNIA.

workers. Frequency distribution of wind direction is commonly represented by a *wind rose,* such as that shown in Fig. 7.4. If this wind rose were applicable to the site under study, it would seem desirable to place the outdoor operation to the north of the other plant buildings for protection, and southeast of the dust-producing unit to avoid the dust. The relatively light and infrequent east and northeast winds would be least harmful in transporting dust. Moreover, the wind roses for January and July suggest that the east and northeast winds are most common during the winter season when rain and snow might interfere with outdoor work. Careful consideration should be given to the possibility that construction of plant buildings might alter the local wind pattern and create undesirable eddies that would require a different solution.

5.5 SCHEDULING

Numerous operations must be scheduled to meet climatic deadlines. Sales are materially reduced unless shipments of antifreeze for cars are in dealers' hands before the first cold spell of the year. Chocolate shipped at temperatures over 87° F may be damaged by heat. Sales of soft drinks, citrus fruits, and ice cream are boosted by a heat wave. Figure 7.1a contains the information necessary to estimate the probability of high temperatures at any time during the year. Figures 7.5 and 7.21i summarize the probabilities that temperatures at or below 32° F will occur on or before any given date in the fall. From charts such as these, the industrial planner can estimate the risk he is taking by scheduling delivery of products for a specific date. He can balance the risk of loss through late delivery against the cost of storage if delivery is too early.

Equally important in the distribution of seasonal products is the possible areal extent of a given weather condition. Figure 7.6 shows the area covered by temperatures over 90° F on August 10, 1944. New York City endured temperatures in excess of 90° F for seven days during this heat wave. Products that would be in demand under such weather conditions must be available in sufficient quantity to serve the area, and should be located at distribution points from which they can be delivered promptly to all points in the area.

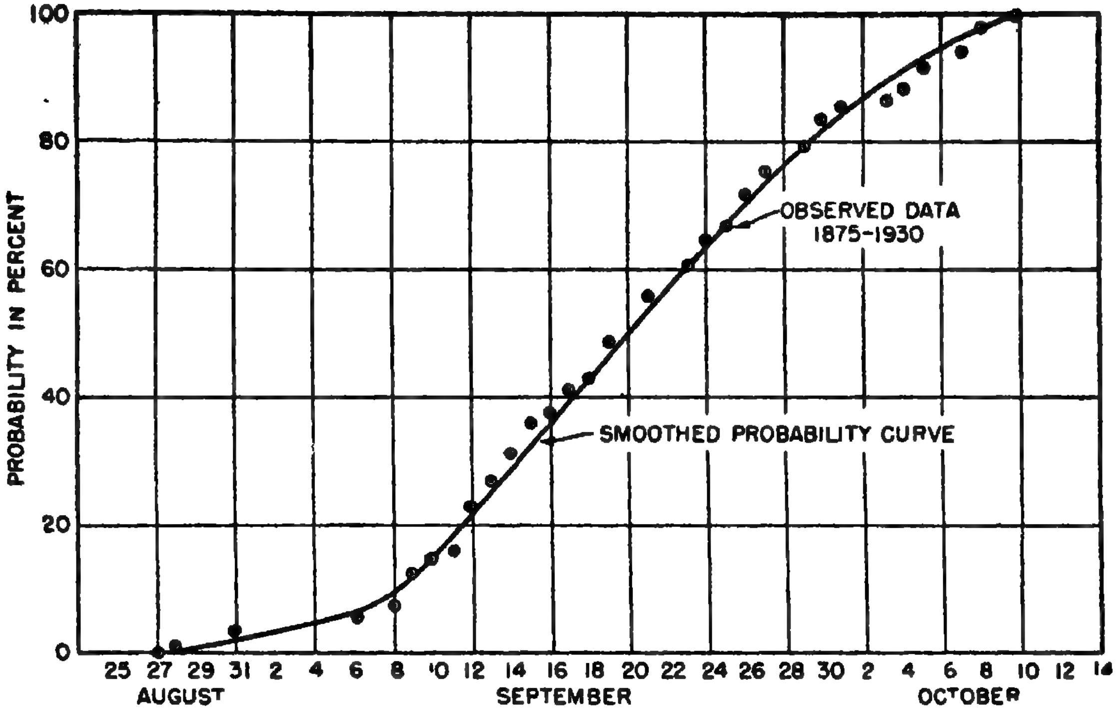
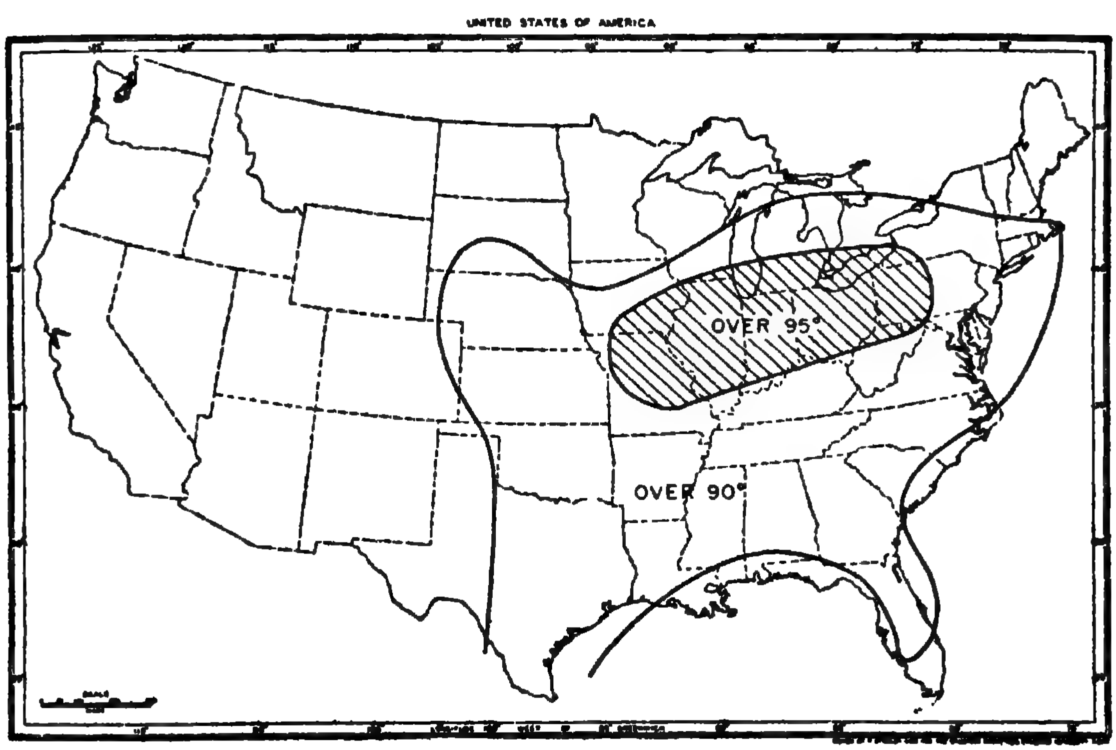


FIG. 7.5 CUMULATIVE PROBABILITY OF THE OCCURRENCE OF 32°F OR LESS PRIOR TO ANY DATE IN THE FALL FOR BISMARCK, NORTH DAKOTA.

FIG. 7.6 AREA COVERED BY THE HEAT WAVE OF AUGUST 10, 1944.



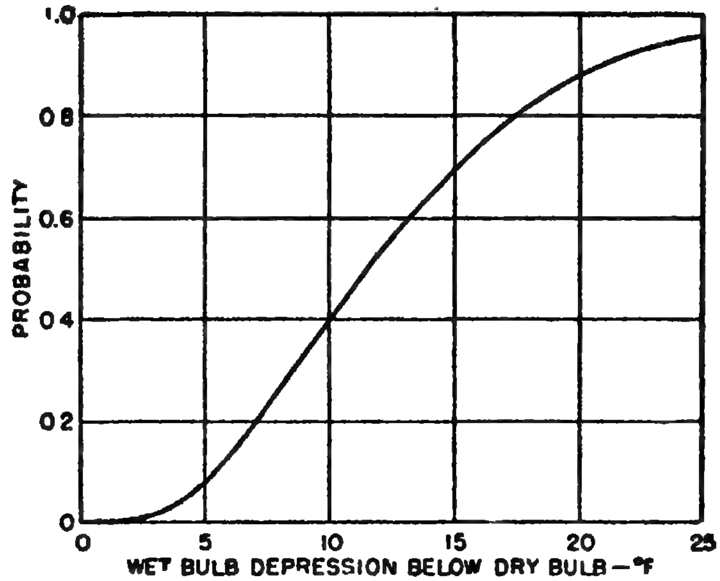


FIG. 7.7 CUMULATIVE PROBABILITY OF WET BULB DEPRESSION, SHREVEPORT, LOUISIANA (U. S. WEATHER BUREAU).

5.6 EQUIPMENT OPERATION

Equipment must be selected to meet the conditions in the area where it is to be used. The wet-bulb depression (Art. 12.1) is a measure of the degree of cooling possible with evaporative-type air-conditioning equipment. Figure 7.7 shows the cumulative probability of various wet-bulb depressions at Shreveport, Louisiana. From a chart of this type, the proper type of equipment could be determined for an installation in the area. Even more useful, however, would be a summary showing the wet-bulb depressions to be expected for various temperatures. Such a joint frequency is shown in Table 7.1, which lists the number of periods of consecutive cloudy days at San Jose, California, and the number of degree days below 65° F occurring during these periods. A table of this type would be helpful in designing sola. heating equipment, since heat storage facilities or auxiliary heating must be supplied to assure adequate heat during cloudy days when solar heating is not satisfactory. Although single-city studies, such as those presented in Table 7.1 or Fig. 7.7, provide a valuable guide in selecting equipment for a given installation, studies for many points are more valuable for determining the best standard sizes for units to meet the diversified conditions that can be expected.

5.7 PRECIPITATION

Precipitation (rain and snow) is an important factor in many industrial problems. Drainage ways for storm water are designed on the basis of precipitation intensity-frequency data.* Snowfall is a factor in roof design in many portions of the country.† Snowfall, temperature, humidity, and wind enter the design of road and walk-way snow-melting systems.‡ Consider an industry involving certain operations that are interrupted by rain. A reserve of

* D. L. Yarnell, *Rainfall Intensity-Frequency Data* (Washington, D. C.: U. S. Department of Agriculture Misc. Publ. 204, 1935).

† *Snow Load Studies* (Washington, D. C.: Housing and Home Finance Agency, Housing Research Paper 19, 1952).

‡ Chapman, W. P., "Design of Snow Melting Systems," *Heating and Ventilating*, Reference Section, April 1952, 96-102.

TABLE 7.1 CONSECUTIVE CLOUDY DAYS AND CORRESPONDING HEATING DEGREE DAYS AT SAN JOSE, CALIF. (Based on 8 years of record)

Degree days \ No. of Days	1	2	3	4	5	6	7	8	9	10	No. of cases	Per cent above class limit
1 to 9	85	15	4			1					105	100
10 to 19	46	18	5	3	1	1					74	67
20 to 29	3	25	4	2							34	43
30 to 39		11	11	12		1					35	32
40 to 49		6	7	6	4		1				24	21
50 to 59			2	4	2	2		1			11	13
60 to 69				4		2	1				7	10
70 to 79	•				2		1	6	1		10	8
80 to 89				2	2		2				6	4
90 to 99						3		1	1		5	3
100 to 109							1			1	2	1
110 to 119												0.3
120 to 130								1			1	0.3
No. of cases	134	75	33	33	11	10	6	9	2	1	314	
No. of days	134	150	99	132	55	60	42	72	18	10		
Per cent of heating days	6	7	5	6	3	3	2	4	1	1		
Cumulative per cent	38	32	25	20	14	11	8	6	2	1		

materials is necessary to permit the rest of the process to continue during the interruptions. A climatological analysis of the frequency of various numbers of consecutive days of rainfall indicates how big this material reserve should be. The same data, used in an economic analysis, might suggest whether or not protection should be provided for the interruptible operation. Such an analysis of rainfall frequency is shown in Fig. 7.8.

5.8 AIR POLLUTION

Since meteorological factors play an important role in the movement of airborne pollutants, a study of the climate of an area will often suggest the problems that may result from a given industrial installation. Strong winds are normally indicative of satisfactory dispersion of contaminants, but if the winds are predominantly from one direction, a

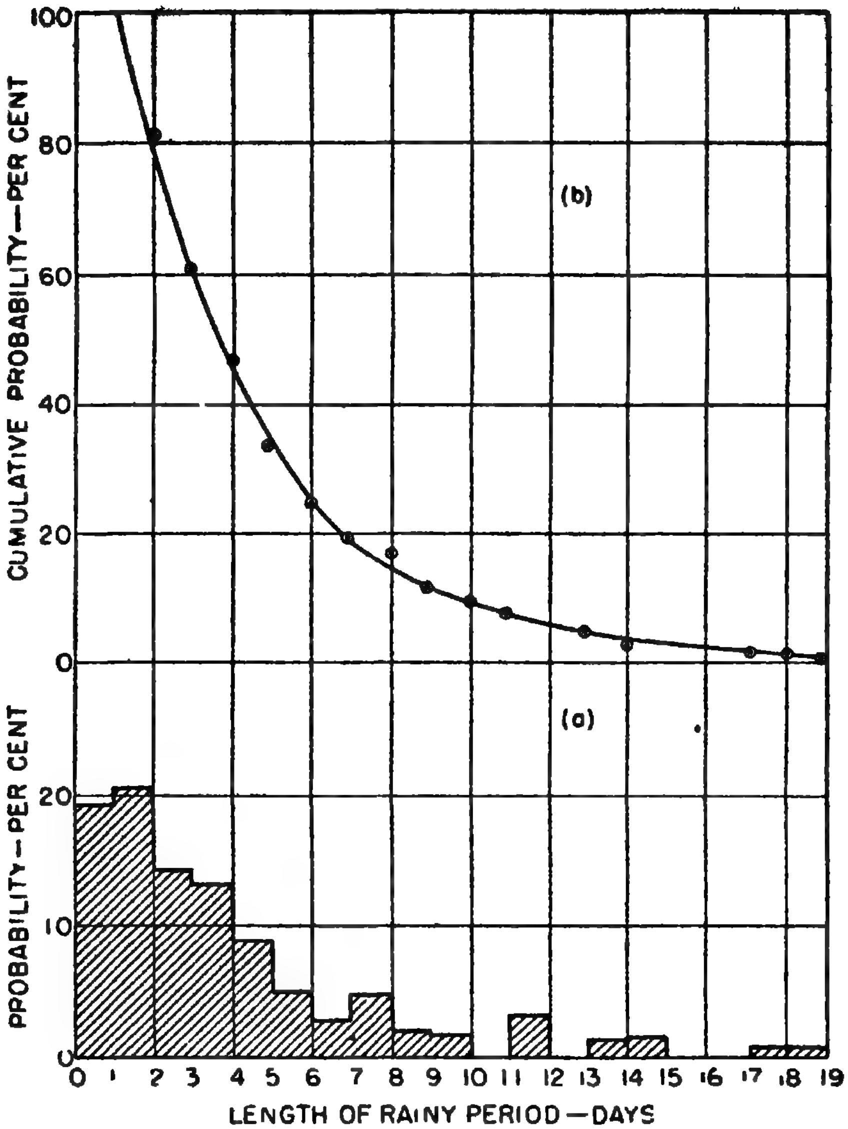


FIG. 7.8 PROBABILITY OF CONSECUTIVE RAINY DAYS AT SAN FRANCISCO, CALIFORNIA. (A) PROBABILITY THAT A RAIN DAY WILL BE ONE OF A SERIES OF VARIOUS LENGTHS. (B) CUMULATIVE PROBABILITY THAT A RAIN DAY WILL BE ONE OF A SERIES EQUAL TO OR GREATER THAN THE INDICATED LENGTH.

narrow strip of land downwind from the source may receive an excessive concentration. Variability in wind direction can be advantageous in spreading pollutant material over a wide area. However, mean monthly or annual wind data, such as were used to prepare the wind roses of Fig. 7.4, may conceal critical diurnal wind variations. Figure 7.9 shows the average hourly wind speed and direction for Santa Maria, California. As at many coastal stations, a land and sea breeze regime predominates, with light variable winds at night. Critical concentrations of pollutants could be expected at night, although the average July wind speed of 7 miles per hour might at first inspection seem adequate for reasonable dispersion.

Under many conditions, dispersion of smoke and gases can be materially improved by increasing effective stack

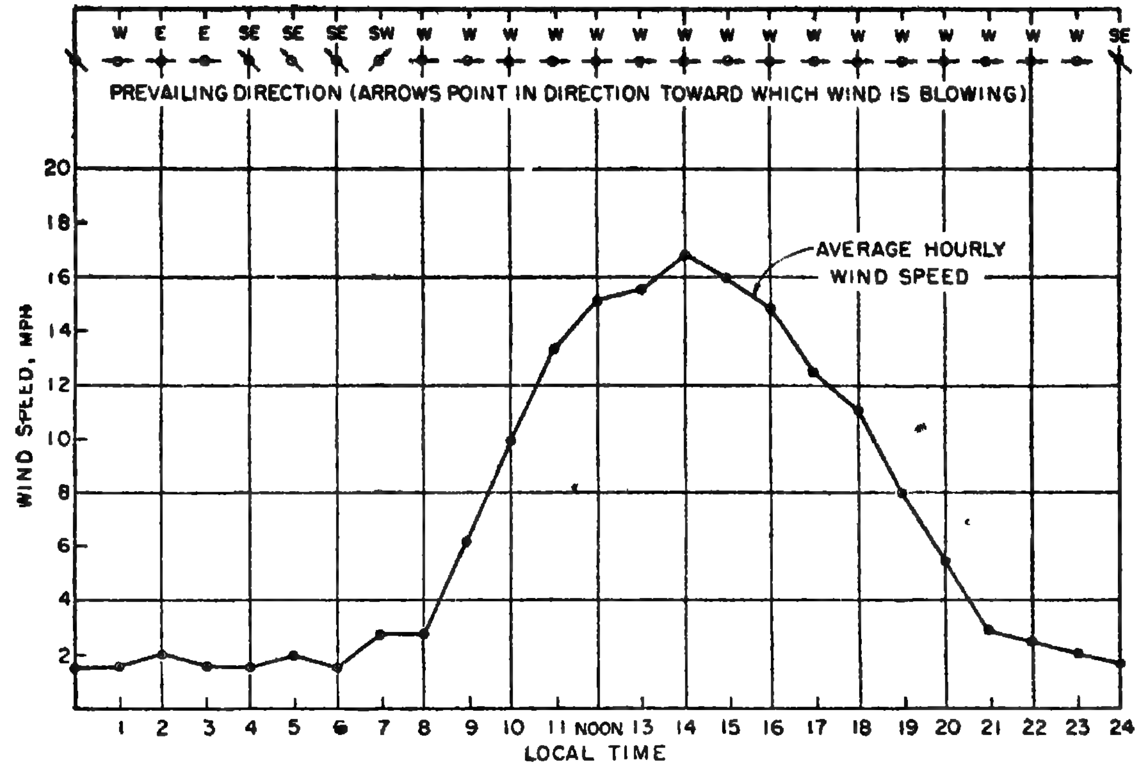


FIG. 7.9 AVERAGE DIURNAL WIND VARIATION FOR JULY, SANTA MARIA, CALIFORNIA.

height or exit temperature. If an *inversion* is common in the area, however, the only solution seems to lie in the use of collection equipment at the stack or in redesign of the process to eliminate the source of nuisance. An inversion (Art. 8.3) is a layer of the atmosphere in which temperature increases with height. Vertical movement of air through such a layer is suppressed and airborne pollutants collect beneath the layer in excessive concentrations. Meteorological analysis can often anticipate the existence of this problem in a new development or assess the magnitude of the problem in areas already faced with air-polution problems.

5.9 HUMAN COMFORT

Human comfort and the effects of clothing are complex problems involving several weather factors. A great deal of experimental work and numerous formulas and charts have been expended on the problem of classifying climate with respect to comfort. One such chart is shown in Fig. 7.10, which utilizes temperature and humidity as parameters.* An average wind velocity of 17 feet per second or 11.6 miles per hour is assumed. A joint frequency analysis of humidity and temperature would permit the climate of a given place to be classified with respect to comfort, as indicated on this chart. It is interesting to note that the range *AA* is considered by Huntington† to be the optimum range for mental work. Range *BB* is considered optimum by British standards, while *CC* is considered optimum in the United States. Climatologists generally agree that a considerable variation in weather is an important feature of a good climate. From the viewpoint of employee morale, comfort outside the plant is almost as

* D. Brunt, "The Reactions of the Human Body to Its Physical Environment," *Quarterly Journal of the Royal Meteorological Society*, Vol. 69, April 1943.

† Ellsworth Huntington, *Civilization and Climate* (New Haven: Yale University Press, 1915), pp. 89-128.

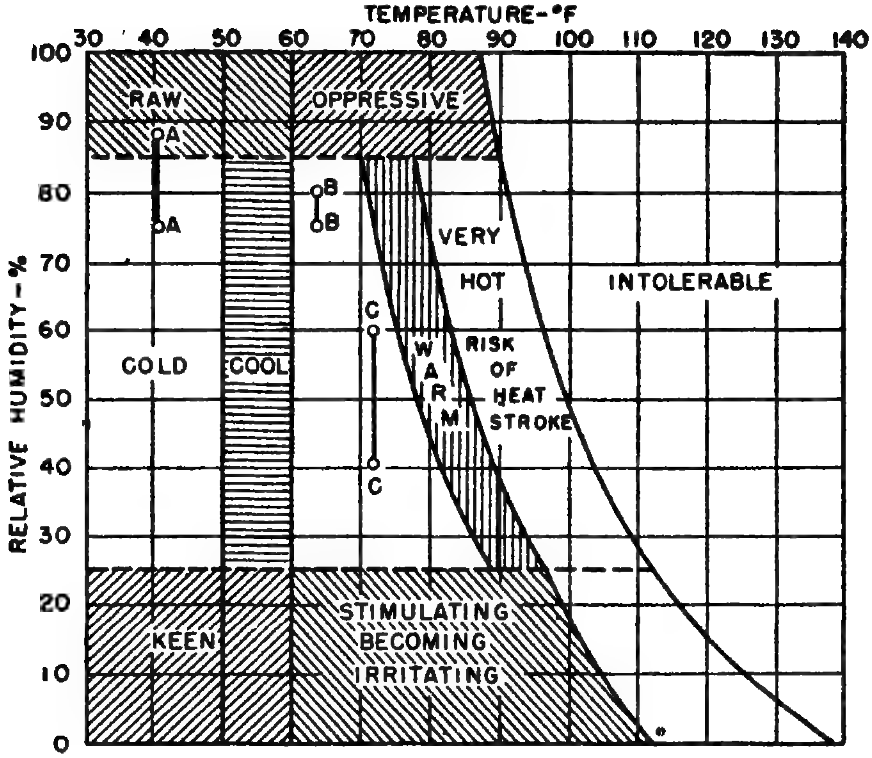


FIG. **7.10** A TENTATIVE CLASSIFICATION OF CLIMATE AS IT AFFECTS HUMAN COMFORT. ASSUMED WIND SPEED OF 17 FEET PER SECOND.

important as working conditions in the plant. The difference between *BB* and *CC* (Fig. 7.10) is suggestive of the differing opinions regarding comfort that result from a natural acclimatization of people exposed over a period of time to a given climate. Climatic comfort involves not only the weather, but also the preferences of the people concerned.

6. SOURCES OF CLIMATOLOGICAL DATA

The main source of climatological data in the United States is the U. S. Weather Bureau, whose archives contain billions of items gathered, for the most part, since the last decade of the nineteenth century. Data are published monthly in *Climatological Data Bulletins* issued for each state. Files of these bulletins are to be found in many libraries and in Weather Bureau offices in the principal cities (Fig. 7.11). Unpublished data may be obtained in the form of photostats, microfilm, or punched-card tabulations. Data for the years 1934-41 and 1948 to date are on punched cards. The Bureau is prepared to provide special services in the tabulation, processing, or reproduction of data at cost.

The most detailed weather records are obtained at approximately 500 Weather Bureau Offices, where hourly observations and automatic instruments provide comprehensive coverage. Volunteer observers at about 9,000 additional stations make daily observations of precipitation and maximum and minimum temperatures. These surface observations are supplemented by upper-air data from about 200 stations in the United States and Alaska.

An extensive summary of climatological data for the United States is given in the *Year Book of Agriculture for 1941, Climate and Man.** A summary of

* See bibliography at the end of this section.

FIG. 7.11 WEATHER BUREAU OFFICES AND SOLAR RADIATION STATIONS IN THE UNITED STATES.

monthly data for all available stations from the beginning of record to 1930 appears in the *Climatic Summary of the United States, Weather Bureau Bulletin W*. World-wide weather records are published annually in the *Réseau Mondial.* Clayton has summarized records at selected world-wide stations for the periods of record in *World Weather Records.*

7. CLIMATIC CHANGES

7.1 FLUCTUATIONS

Perhaps the most evident feature of weather is its variability. The various elements of weather at any point on the earth's surface are continuously fluctuating about a value called the normal. Since the basis of most climatological studies is the assumption that the weather of the past is a guide to the weather of the future, it is important to know whether this normal is fixed or variable.

Ahlmann* distinguishes between *climatic variations*, or trends measured in terms of geologic time, and *climatic fluctuations* observable in a period as short as the human life span. Geological evidence clearly demonstrates the existence of climatic variations Some parts of the world have experienced a change from near-polar climate to tropic climate over a period of some 50,000 years. This is a warming of about 0.001 F° per year, an insignificant quantity in most climatological studies. Superimposed on these variations are fluctuations of shorter period and greater magnitude. Kincer† concludes that a definite upward trend in temperature persisted from about 1860 to 1940. At Washington, D. C., this change seems to be about 2 F°, or about 0.02 F° per year. Ahlmann finds somewhat larger fluctuations in Sweden. Precipitation records provide less conclusive evidence of fluctuation, and the lack of long records for other elements makes it difficult to study trends in humidity, wind, cloudiness, and so forth. Brier* finds a definite decrease in air pressure in the Northern Hemisphere during the period 1900 to 1940.

Changes in observation techniques may be responsible for at least part of the apparent trends that have been noted. It has been suggested that artificial heating in cities is responsible for apparent upward trends in temperature, although this seems to be discounted by the existence of similar trends at rural exposures. Increased height of buildings and expansion of cities have increased frictional resistance to wind and lead to an apparent downward shift in wind speed in some cities. Average annual wind speed at Detroit, Michigan, decreased from 15 to 9 miles per hour between 1909 and 1939.

It may be concluded that natural trends are too small to be of importance in industrial climatology, but that changes caused by man's activities may be large enough to require special treatment. As a precaution, the data used in climatological studies should be the most recent available, and the record period used should be as short as possible consistent with requirements of an adequate statistical analysis. These limitations will minimize the effects of trends in the data, whatever their cause may be.

7.2 CYCLES

A casual inspection of any series of meteorological data reveals fluctuations that seem to be roughly cyclical. A great deal of study has been given to determining the period and amplitude of such cycles and to explaining them through correlation with other cyclical phenomena such as sunspots and planetary movements. The results of these studies are not particularly conclusive.

* H. W. Ahlmann, "The Present Climatic Fluctuation," *Geographical Journal,* Vol. 112, June 1947, 165-195.

† J. B. Kincer, "Our Changing Climate," *American Geophysical Union Transactions,* Vol. 27, 1947, 342-347.

* G. W. Brier, "Forty-year Trend in Northern Hemisphere Surface Pressure," *Bulletin of the American Meteorological Society,* Vol. 28, 1947, 237-247.

Fourier analysis carried to a sufficient number of terms will produce a reasonable fit for almost any series of climatic data. Serial correlation analysis suggests, however, that most climatic series are entirely random. Various investigators have identified nearly 100 "cycles" in climatic data, ranging from one year to 744 years in length.* None of these cycles or combinations of cycles have proved useful in predicting future weather. In the light of present knowledge, it seems best to consider climatic data as random series.

The only clearly established cycles are the annual and diurnal ones, and even these are rarely identical. The earth-sun relationships responsible for daily fluctuations in temperature, wind, and humidity, and the annual march of almost all meteorological elements assure variations that are roughly similar from day to day and year to year.

7.3 PERSISTENCE

Persistence is a term applied to the tendency of a weather condition, once established, to continue for a period of time. Storms that bring rain are large air masses requiring time to move past a given point. Hence rain will persist until the system has moved from the area. Long-period persistence develops when a series of similar systems moves across an area; a given type of weather continues with minor interruptions for the time necessary for the series to pass. The circulation patterns that bring hot, dry weather to an area may be more common in some years than in others. The result is a dry year or drought. Since the reasons for the development of conditions of this type are only imperfectly understood, from the climatological viewpoint persistence is treated as a random occurrence—i.e., two rainy days in sequence will be common, three less frequent, four still less frequent, and so on (Fig. 7.8), much as would be expected for the occurrence of successive heads on the toss of a coin.

* Sir Napier Shaw, *Manual of Meteorology*, Vol. 2, 2nd ed. (London: Cambridge University Press, 1942), pp. 320-325.

8. TEMPERATURE

8.1 MEASUREMENT

The most commonly observed temperatures are the daily maxima and minima measured about five feet above the ground in a white-painted, wooden shelter with louvered walls and double roof. Maximum temperature is observed by means of a mercury thermometer that functions like a clinical thermometer—i.e., the mercury rises freely but is restrained from falling by a constriction in the bore. Minimum temperature readings are obtained from an alcohol thermometer that has a small glass index in the bore. Surface tension of the alcohol draws the index down as temperature falls, but as temperature rises the alcohol flows past the index. The position of the upper end of the index indicates the minimum temperature since the last setting. Both thermometers are exposed in nearly horizontal positions. The shelter protects the thermometers from direct solar radiation so that they will record free-air temperature at a level approximately that of a person's head. Continuous records of temperature are obtained at Weather Bureau Offices from *thermographs*, in which a bimetallic or liquid-filled element actuates a pen on a clock-driven chart. Since these instruments are less accurate than the thermometers, their records are ordinarily adjusted to conform to the observed maximum and minimum temperatures.

8.2 TERMINOLOGY

The following definitions cover the most commonly used temperature expressions and are in accord with U. S. Weather Bureau usage.*

* A. H. Thiessen, *Weather Glossary* (Washington. D. C.: U. S. Weather Bureau, 1946).

Mean daily temperature is the average of the maximum and minimum temperatures for the day. This value is usually slightly high, but within a degree of the true average temperature for the day. The magnitude of the bias varies somewhat with the time of observation.*

Daily range is the difference between the maximum and minimum temperatures for a given day.

Mean monthly temperature is the average of the mean monthly maximum and minimum temperatures.

Absolute monthly range is the difference between the highest and lowest temperatures during the month.

Mean annual temperature is the average of the 12 monthly mean temperatures for the year.

Annual range is the difference between the mean temperatures of the warmest and coldest months of the year.

A *degree day* is a departure of one degree per day from a selected reference temperature. Most published degree-day data are based on departures below 65° F, a measure of heating required in buildings. A day with a mean daily temperature of 60° F represents five degree days below 65° F. If the daily temperature fluctuates above and below the reference value, degree days computed from the mean temperature will usually be less than those determined by summing the degree hours for the day and dividing by 24. Under some circumstances, the difference may be quite large.

8.3 AREAL VARIATIONS IN TEMPERATURE

Two types of areal variations in climatic elements may be noted: (1) those resulting from the conditions of exposure of instruments, and (2) point-to-point differences with uniform exposure. The standard thermometer shelter is intended to create a uniform exposure condition for the instruments. Different types of shelters (or no shelters at all) may result in differing temperatures on thermometers only a few feet apart. The temperature within a shelter is an *index* to temperatures near the shelter, but it is not intended to be a quantitative *measure* of these conditions. The temperature of a surface exposed to the direct rays of the sun will be substantially higher than the "official temperature." Temperatures in or near a building will differ from shelter temperatures, depending on the type of construction and the extent of artificial heating or cooling. Any climatological analysis of temperature must view the shelter temperature in the light of the actual temperature conditions at the point of interest. Published temperature data must either be treated as a statistical index of the temperature influence being studied or be adjusted for the differences in conditions of exposure.

Large variations in temperature may be observed when thermometers are exposed in standard shelters in different locations. Some of the macro-variations in normal annual temperature are depicted in Fig. 7.12. The most obvious variation is with latitude, as indicated by the general east-west alignment of isotherms (lines of equal temperature) in the eastern United States. Since large bodies of water exert a stabilizing influence on temperature, winter isotherms bend southward along the coasts and summer isotherms are diverted northward. The annual range of temperature is therefore lower along the coasts than in the interior. The effect of topography is evident in the greatly distorted pattern of the western states, with generally lower temperatures in regions of high elevation.

Micro-variations in temperature are controlled by much the same factors as are the large-scale variations. Large lakes modify the temperature regime of the immediate area.* Vegetation has a stabi-

* W. F. Rumbaugh, "The Effect of Time of Observation on the Mean Temperature," *Monthly Weather Review*, Vol. 62, 1934, 375-376.

* J. Leighly, "Effects of the Great Lakes on the Annual March of Temperature in Their Vicinity," *Papers of the Michigan Academy of Arts, Science, and Letters*, Vol. 27, 1941, 337-414

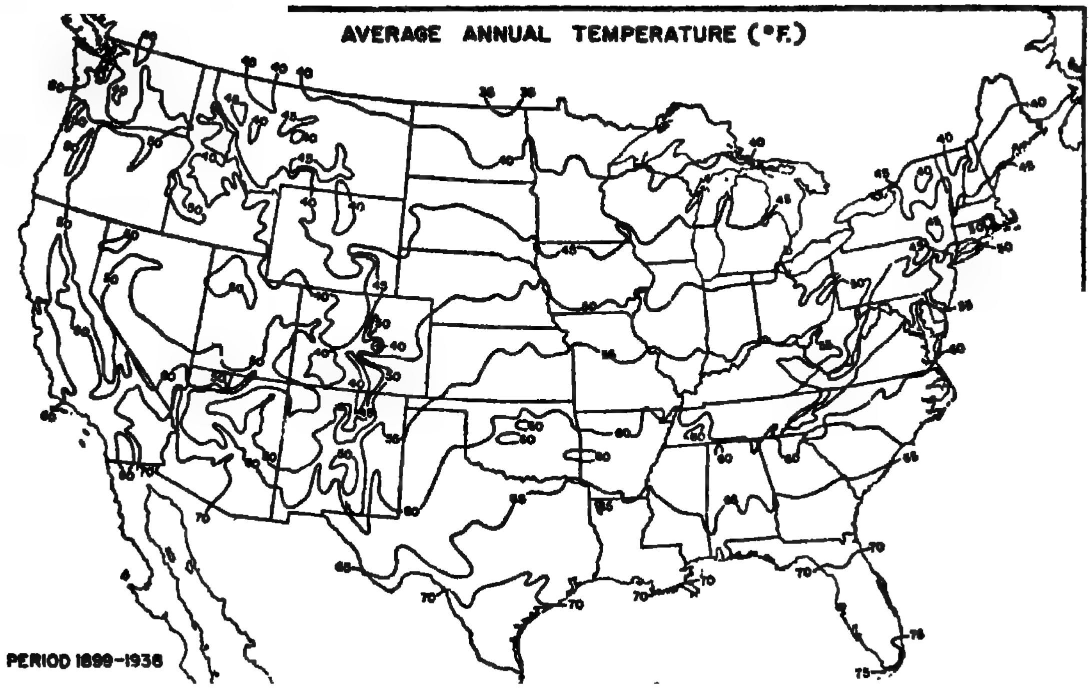


FIG. 7.12 NORMAL ANNUAL TEMPERATURE (°F) IN THE UNITED STATES (U. S. WEATHER BUREAU).

lizing effect, and maximum temperature, daily range, and annual range are usually lower at stations in a forest than at stations in open country. The artificial heat of cities and the shielding effect of haze and smoke result in higher temperatures than in the immediately surrounding country. The difference is often as much as 2 F°, resulting mainly from higher minimum temperatures in the cities.

Probably the most important factor controlling temperature is topography. If dry air is forced to rise, it expands, because of lower pressure, and therefore cools. Assuming an adiabatic process (no heat exchange between a rising air particle and its environment), free-air temperature decreases about 0.5 F° per 100 feet of elevation. Air lifted above its condensation level becomes saturated and cools at about 0.3 F° per 100 feet because of the latent heat of condensation released by the moisture. If the cooling and condensation of moisture in the air result in precipitation, the thermal process is not reversible, and when the air descends on the leeward slope of the mountain it is warmed at the dry adiabatic rate. Level for level, warmer temperatures are experienced on the leeward slopes of mountains than on the windward slopes. The *Chinook* or *foehn* wind—a warm, dry, downslope wind—is the result of this process.

The average rate of temperature decrease with height assumed in the U. S. Standard Atmosphere (Table 7.2) is about 0.36 F° per 100 feet near the ground. In general, we may expect a temperature decrease between 0.3 and 0.4 F° per 100-foot increase in altitude. This condition will exist only when the wind is strong enough to keep the air well mixed. Under still air conditions, radiative cooling of the ground results in a rapid lowering of the ground surface temperature at night, and an *inversion* or increase of temperature with height may develop. Under these conditions, frost may occur at the ground surface with above-freezing temperatures in the instrument shelter. An inversion may also form aloft, creating a thermal stratification beneath which smoke and dust tend to collect. Without strong

TABLE 7.2 VARIATION OF PRESSURE, TEMPERATURE, AND BOILING POINT WITH ELEVATION*

Elevation (Ft. above mean sea level)	Pressure		Air temperature °F	Boiling point °F
	Inches of mercury	Millibars†		
−1,000	31.02	1050.5	62.6	213.8
0	29.92	1013.2	59.0	212.0
1,000	28.86	977.3	55.4	210.2
2,000	27.82	942.1	51.8	208.4
3,000	26.81	907.9	48.4	206.5
4,000	25.84	875.0	44.8	204.7
5,000	24.89	842.9	41.2	202.9
6,000	23.98	812.1	37.6	201.1
7,000	23.09	781.9	34.0	199.2
8,000	22.22	752.5	30.6	197.4
9,000	21.38	724.0	27.0	195.6
10,000	20.58	696.9	23.4	193.7
11,000	19.79	670.2	19.8	191.9
12,000	19.03	644.4	16.2	190.1
13,000	18.29	619.4	12.6	188.2
14,000	17.57	595.0	9.1	186.4

* Data represent average free-air conditions.
† The meteorological unit of pressure equivalent to 1,000 dynes per square centimeter.

winds, the cooling of the surface air may lead to *air drainage*, the flow of the cold air downslope. As a result, valley temperatures may be lower than those on the adjacent hills.

8.4 ADJUSTMENT OF TEMPERATURE RECORDS

The factors described in the preceeding paragraphs mean that moving a temperature station may easily result in changes in observed temperatures. One method for detecting and correcting such changes is to plot the temperature data from the station in question against the average temperature at several nearby stations which are known to be unchanged (Fig. 7.13). A change in the conditions of observation will ordinarily be indicated by a shift in the relation. The adjustment may be different for maximum and minimum temperatures and may also vary during the year. A relation of this type may be used to estimate missing records or to extend the station record to the years prior to the actual beginning of observations. The importance of such an adjustment depends on the problem under study, but its magnitude should certainly be investigated for all stations known to have been moved. Since records of station moves during the early years of the Weather Bureau are rather inadequate, a test for all stations is preferable. Figure 7.14 indicates the magnitude and frequency of temperature differences that may be expected between two stations a short distance apart. The Sleepy Hollow station is about six miles SSW and about 350 feet higher than the Washington, D. C., City Office. Note the difference between maximum and minimum temperatures and the seasonal variations.

9. PRECIPITATION

9.1 MEASUREMENT

Precipitation amounts are expressed in terms of the depth of liquid water that would accumulate on

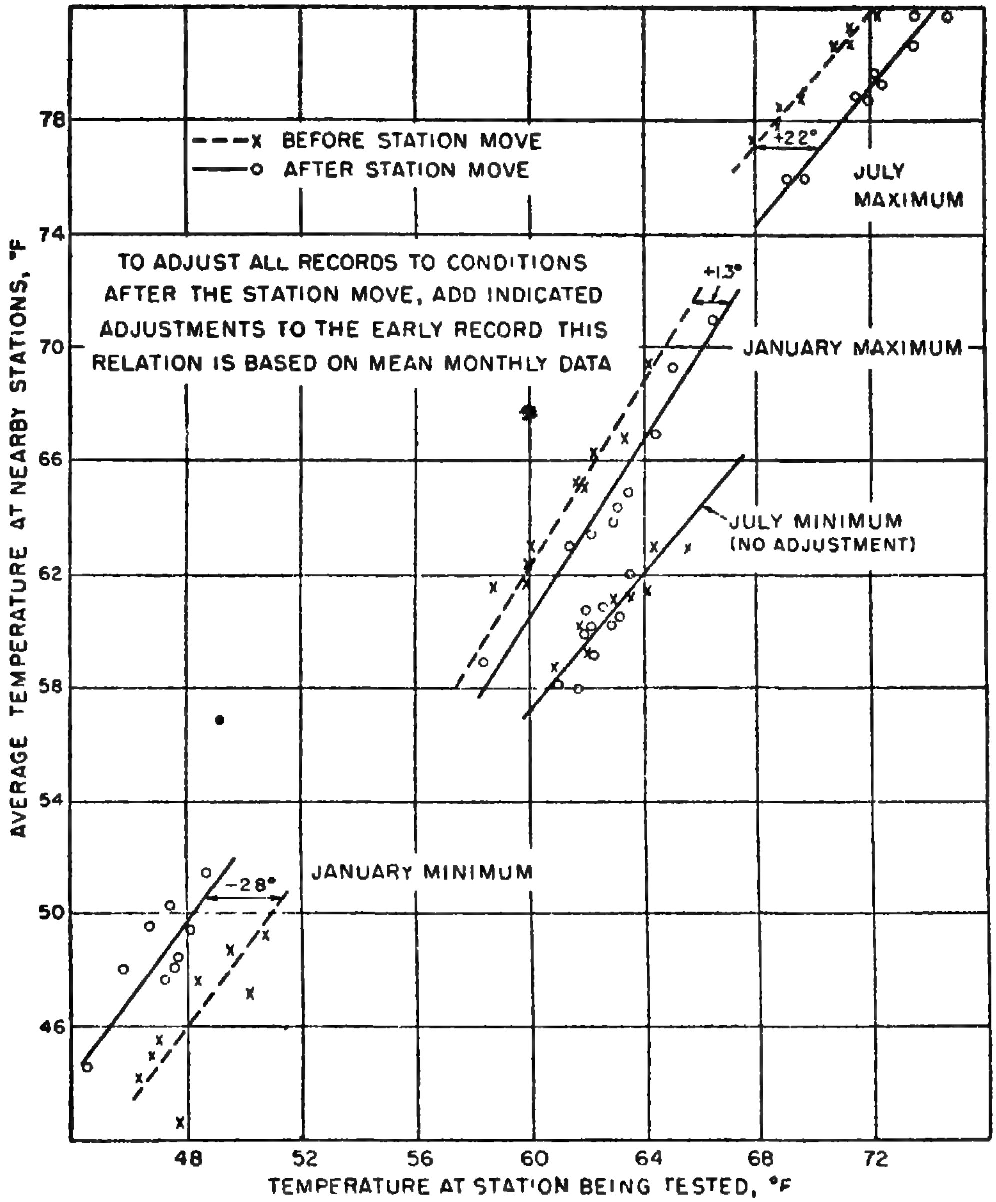


FIG. 7.13 RELATION FOR ADJUSTING TEMPERATURE RECORDS FOR EFFECT OF A STATION MOVE.

a horizontal surface. The official gage of the U. S. Weather Bureau consists of a funnel 8 inches in diameter which discharges into a measuring tube 2.53 inches in diameter. An outer container 8 inches in diameter serves as an overflow can. The ratio of areas between funnel and measuring tube is 10:1 so that the depth in the tube can be measured to the nearest 0.01 inch of precipitation on the 8-inch funnel with a scale graduated to 0.1 inch. Snow is measured by removing the funnel and catching the precipitation in the overflow can. The snow is melted and poured into the measuring tube so that its water equivalent can be measured. Numerous gages of smaller diameter are in use. They are usually as accurate as the larger gage for measuring rainfall but are unsatisfactory for measuring snowfall.

The most common type of recording gage used to obtain data on short-period rainfall intensity is the weighing gage. A collecting bucket is mounted on a platform supported by a spring or lever scale and the increase in weight is recorded on a chart. The tipping bucket

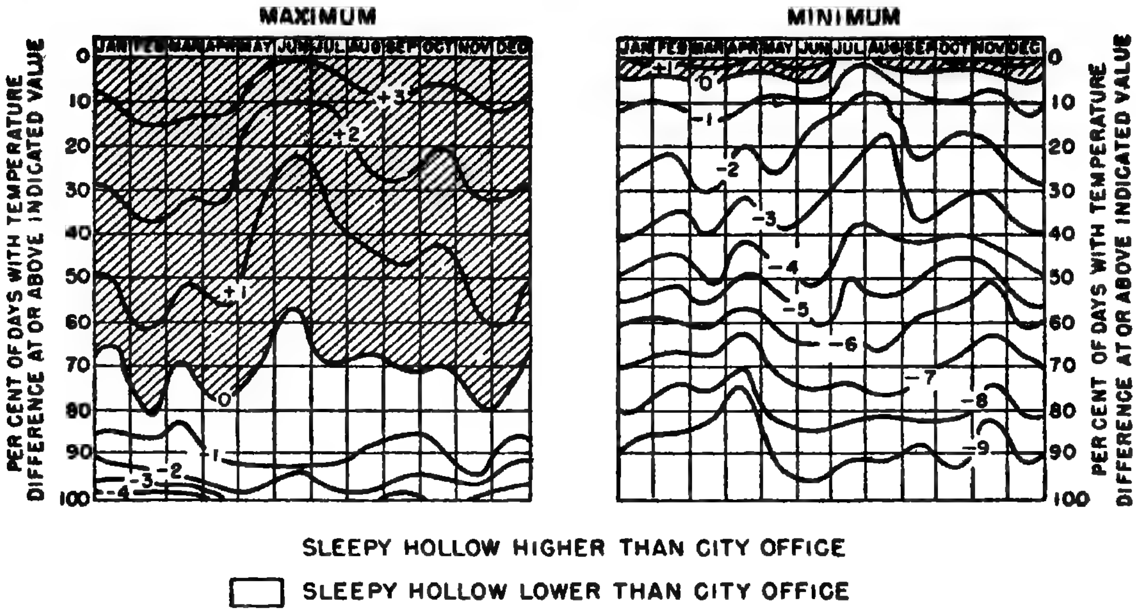


FIG. 7.14 FREQUENCY OF DAILY MAXIMUM AND MINIMUM TEMPERATURE DIFFERENCES BETWEEN WASHINGTON, D. C. CITY OFFICE AND SLEEPY HOLLOW, VIRGINIA, 1942-44 (U. S. WEATHER BUREAU).

gage consists of a pair of small buckets mounted under a funnel in such a way that when one receives 0.01 inch of precipitation, it tips and discharges its contents and at the same time brings the other bucket under the funnel. Each tip of the buckets is recorded on a chart. The tipping bucket records are usually more satisfactory for determining rainfall rates for periods of less than an hour, but the gage is not very suitable for measuring snowfall.

The exposure of the gage has more effect on the accuracy of rainfall records than does the type of gage used. The gage should be far enough from trees or buildings so that it is not sheltered from rainfall. On the other hand, strong winds tend to deflect a portion of the precipitation from the gage and result in catches that are too low. Some protection by low bushes, trees, or buildings about as far from the gage as their own height is desirable. No quantitative basis is available for suggesting the errors resulting from differing exposures, but in studies in which quantity of rain is important, records from severely windswept sites should be viewed with some suspicion unless a special windshield has been used on the gage.

9.2 SNOW

Snow on the ground is measured in inches of depth with any convenient scale. To allow for variations resulting from local melting or drifting, the reported depth should be an average of several readings in the vicinity of the station. All cooperative observers of the Weather Bureau are asked to record snow depth, but these data are not published and must be obtained from the Bureau files.

9.3 CAUSE OF PRECIPITATION

Macro-variations of precipitation (Fig. 7.15) are dependent on nearness to a moisture source, topography, and latitude. Since the moisture content of the atmosphere is a function of temperature, there is a greater amount of

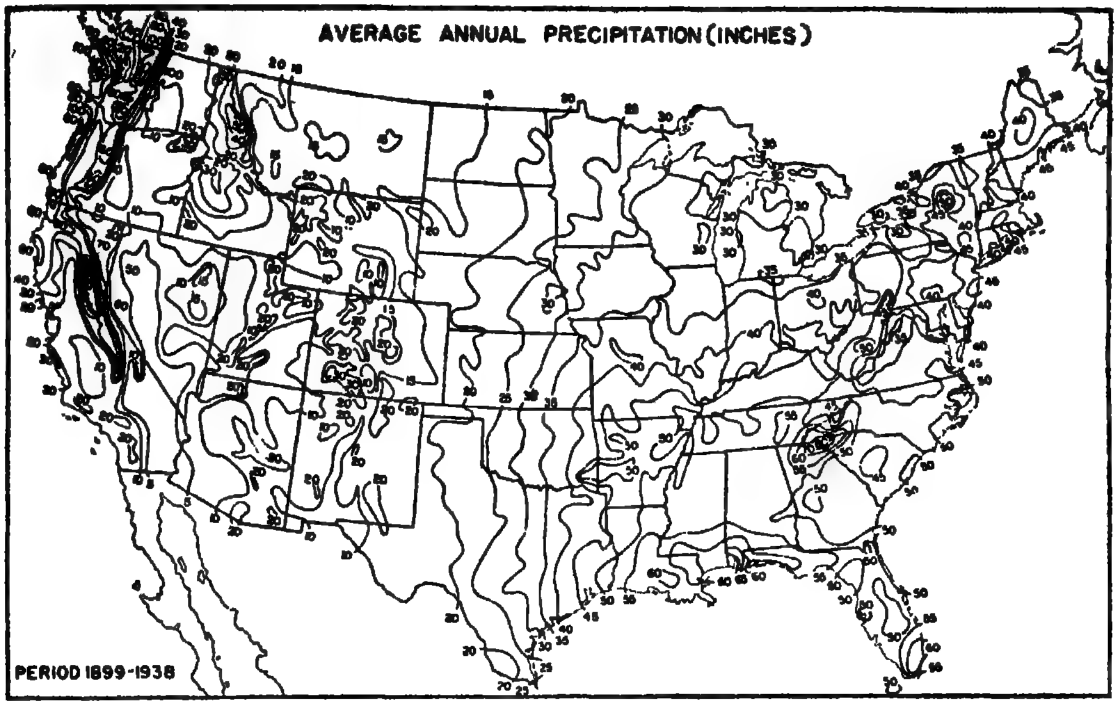


FIG. 7.15 NORMAL* ANNUAL PRECIPITATION (INCHES) IN THE UNITED STATES (U. S. WEATHER BUREAU).

water available for precipitation in the lower latitudes. With the oceans as the source of moisture for precipitation, it is also natural to find greater amounts of precipitable water along the coastlines than in the interior of continents. Evaporation from lakes and land surfaces, and transpiration of moisture by plants, are not major sources of atmospheric moisture.* Nor do man-made lakes materially affect the precipitation regime of an area. Moisture alone is not sufficient to bring heavy precipitation to an area. A mechanism capable of converting atmospheric water vapor to liquid water is essential. This is accomplished by cooling the air. The only means of cooling large air masses sufficiently to produce heavy precipitation is by lifting, which causes cooling by expansion (Art. 8.3). The three basic lifting processes are frontal, convective, and orographic.

A *front* is the boundary between two air masses of differing characteristics. A warm front is one in which the air behind the front is warmer than that preceding the front. A cold front is the reverse—i.e., the colder air follows the front. The warm, moist air following a warm front rises over the colder air in advance of the front. This lifting results in condensation and perhaps precipitation. Warm-front precipitation is usually gentle and continuous for a fairly long period. A cold front pushes under the warmer air in advance, lifting is more rapid, and precipitation is more intense but of shorter duration. Many cold fronts are accompanied by thunderstorms.

Convectional lifting takes place when an air mass is warmed from below and tends to rise through cooler air surrounding it. The thunderstorms of the eastern United States are convectional storms and result in very intense but localized precipitation. Convectional thunderstorms may bring rain to areas as small as four or five square miles while the surrounding country receives little or no rainfall.

* G. S. Benton, R. T. Blackburn, and V. O. Snead, "The Role of the Atmosphere in the Hydrologic Cycle," *American Geophysical Union Transactions*, Vol. 31, Feb. 1950; 61-73.

Mountains form *orographic barriers* over which air masses must rise. If the air contains sufficient moisture, the mountains become regions of high precipitation. Because mountains are fixed barriers causing the rain to occur at the same place each time, rainfall is usually higher than in regions of frontal activity where the moving front distributes the precipitation over large areas. The more rapidly air is lifted, the greater the amount of moisture condensed. Therefore, the steeper the mountain slopes, the greater the precipitation. Orographic precipitation is distinguished by the regularity of the precipitation pattern. Areas of high and low precipitation remain reasonably stable from storm to storm. Because air is descending on the lee slopes of a mountain, a *rain shadow* or region of low precipitation is usually present on the slopes away from the prevailing wind. Rain drops do not fall vertically from their point of formation; rather, they describe a trajectory to leeward that is determined by wind speed and drop size. Hence leeward slopes immediately beyond a mountain crest may receive fairly high precipitation as a result of carry-over of rain formed during the ascent on the windward slope.

9.4 AREAL VARIATIONS OF PRECIPITATION

Areal variations of precipitation are somewhat more difficult to rationalize than those of temperature. In regions of little relief, areal variations from storm to storm may be quite large, but, in the average over long periods of time, the differences from point to point will be small because of the random location of the storm centers. In such regions one can interpolate linearly between rainfall stations to estimate normal monthly or annual rainfall at ungaged points. If there is substantial topographic relief, the situation is quite different. Large variations in precipitation may be observed over very short distances and linear interpolation may be quite inaccurate. Some success has been reported * in use of multiple correlations between precipitation and topographic factors as a basis for estimating normal annual rainfall in mountain regions. Vegetal types, erosion conditions, and other factors affected by rainfall offer further clues to the rainfall pattern in mountains.

9.5 ADJUSTMENT OF PRECIPITATION RECORDS

Few precipitation stations have remained in exactly the same location throughout their period of record. In some instances, a station move has involved a large change in exposure conditions without a corresponding change in name. Such records may be adjusted by use of the *double mass curve.*† A double mass curve is constructed by plotting the mass accumulation of precipitation at the station to be tested against a comparable mass accumulation for the same years at a group of control stations in the immediate area (Fig. 7.16). A change in the rainfall regime of the station is indicated by a change in slope of the double mass curve. The station records may be adjusted by multiplying the older records by the ratio of the slopes of the double mass curve before and after the change in slope. The method is somewhat subjective and caution is necessary to avoid interpreting random variations about the double mass curve line as critical changes in slope. Analysis of variance may be used to indicate the probable significance

* W. C. Spreen, "A Determination of the Effect of Topography on Precipitation," *American Geophysical Union Transactions*, Vol. 28, April 1947, 285-290.

† M. A. Kohler, "Double-mass Analysis for Testing the Consistency of Records and for Making Required Adjustments," *Bulletin of the American Meteorological Society*, Vol. 30, 1949, 188-189.

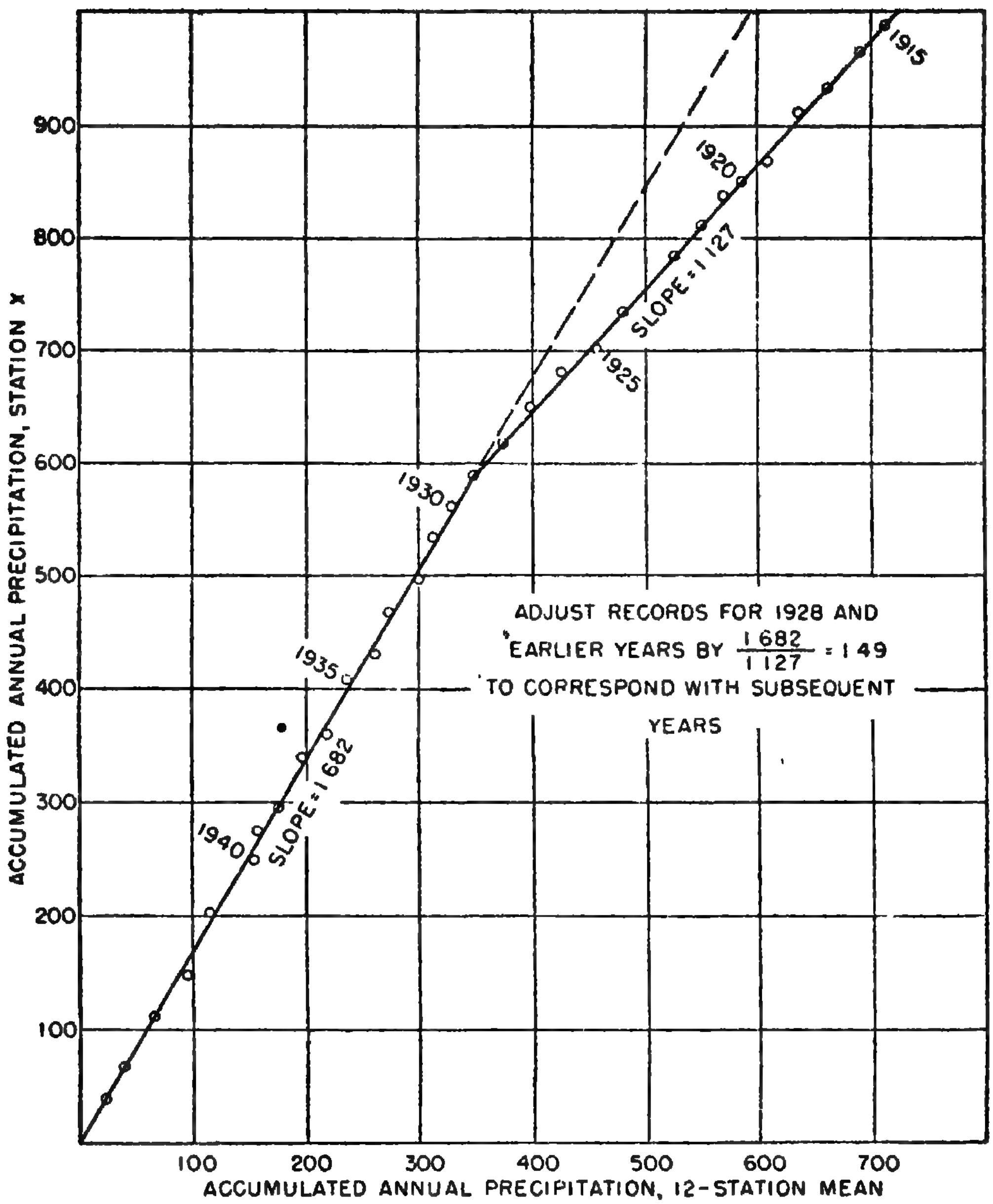


FIG. 7.16 DOUBLE-MASS CURVES FOR ADJUSTMENT OF PRECIPITATION RECORD.

of an apparent change in slope if no record of an actual station move exists. Missing records at a station may be estimated by multiplying records from adjacent stations by the ratio of slopes of the respective mass curves. The double mass curve assumes the existence of a relation between precipitation amounts at nearby stations. Although this assumption is valid for annual and monthly precipitation, it may not be for daily records.

10. SUNSHINE AND CLOUDINESS

10.1 OBSERVATIONS

Three types of observations provide data on sunshine, solar radiation, and sky cover. The most common observations are those of state of the sky. All cooperative observers are asked to record the condition of the sky at observation time as either clear, partly cloudy, or cloudy. These are subjective

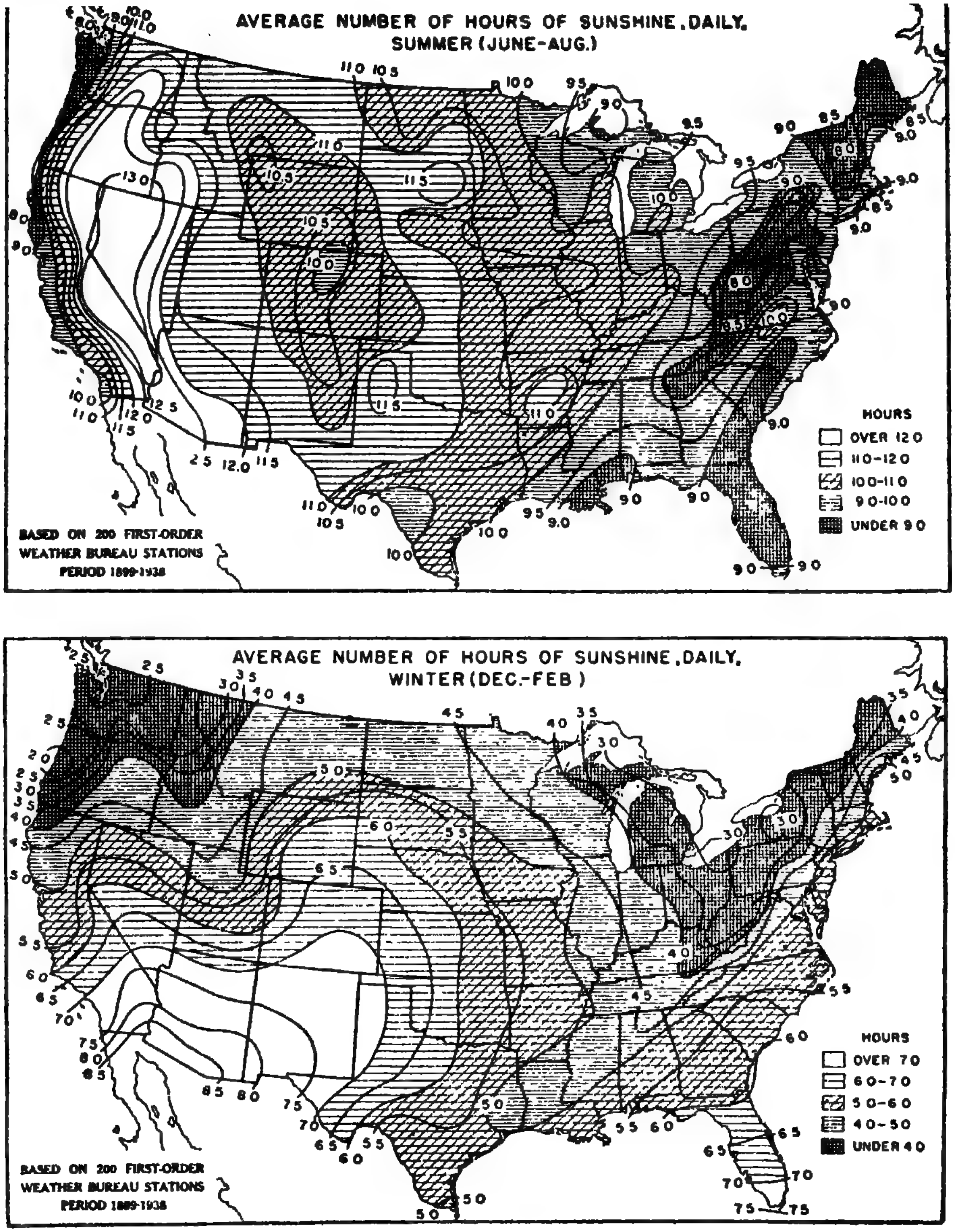


FIG. **7.17** AVERAGE DAILY NUMBER OF HOURS OF SUNSHINE IN THE UNITED STATES (U. S. WEATHER BUREAU).

observations and are of limited value, because they represent only conditions at one instant during the day. Regular offices of the Weather Bureau observe cloud cover hourly and express the observation in tenths of the sky covered by clouds. The observations are made by trained observers and are more reliable than those made by cooperative observers. The average of the hourly observations is the daily cloudiness. The rules governing these observations are

such that a complete overcast of high cirrus clouds is reported as 10/10 cloudy, although much radiation reaches the ground. Quantitative estimates of radiation reaching the ground must be based on cloud type as well as cloudiness. Haurwitz* has developed an equation expressing insolation as a function of cloud type and density.

Sunshine duration indicators in use at many stations consist of a mercury switch so arranged that incident radiation causes the mercury to expand and close a circuit; the circuit is also closed at one-minute intervals by another switch controlled by a time clock. If both switches are closed simultaneously, an indication is made on a chart. The time of sunshine and its total duration to the nearest minute are obtainable from the chart. The threshold radiation that will activate the indicator depends upon its adjustment. Records from two offices may not be exactly comparable because of differing threshold settings.

Solar radiation is measured with *pyrheliometers* at about 50 stations in the United States (Fig. 7.11). The Epply pyrheliometer is most common. This device consists of a series of concentric rings painted alternately black and white and exposed in a glass globe. The current developed by the temperature difference between the black and white rings is a measure of the incident radiation. The usual chart record shows instantaneous values of incident radiation and must be integrated to determine daily totals. The customary unit is the *langley* (*ly*), which is one gram calory per square centimeter. One langley is equivalent to 3.69 Btu per square foot.

10.2 VARIATIONS

Generally speaking, geographical variations of sunshine (or cloudiness) are not large. Except under special conditions, one can usually transpose records of sunshine or cloudiness over fairly large areas. Along coastlines, where the persistence of fog varies widely, the only safe basis for estimates of this condition are local observations. Similarly, local smoke and dust (smog) may reduce the sunshine received in cities. Figure 7.17 shows maps of average daily hours of sunshine in the United States during the winter and summer. Marked seasonal differences are evident. The amount of radiation reaching the ground depends both on the duration of sunshine and on the extent of interception of radiation by the atmosphere. Even 5,000 feet of clear air will reduce the radiation received at the ground by as much as 10 per cent.* Because of the very few solar radiation stations in the United States, the data for the map of Fig. 7.18 were obtained for the most part by computing radiation Q from

$$Q = Q_0(0.35 + 0.61S) \qquad (1)$$

where Q_0 is the cloudless-day radiation and S is the per cent of possible hours of sunshine.† The values on the map indicate radiation received on a horizontal plane at the earth's surface.

11. WIND SPEED AND DIRECTION

11.1 OBSERVATIONS OF WIND SPEED

Wind-speed records are obtained at almost all Weather Bureau offices from instruments known as *anemometers*. The most common type of anemometer consists of three cups rotating about a vertical axis. Contacts are provided for each sixtieth mile of wind. By counting the number of contacts per minute, the average velocity

* B. Haurwitz, "Insolation in Relation to Cloudiness and Cloud Density," *Journal of Meteorology*, Vol. 2, September 1945, 154-166; Vol. 3, December 1946, 123-124; Vol. 5. June 1948, 110-113.

* I. F. Hand, J. H. Conover, and W. A. Boland, "Simultaneous Pyrheliometric Measurements at Different Heights on Mt. Washington, N. H.," *Monthly Weather Review*, Vol. 71, May 1943, 65-69.

† S. Fritz and T. H. MacDonald, "Average Solar Radiation in the United States," *Heating and Ventilating*, Vol. 46, July 1949, 61-64.

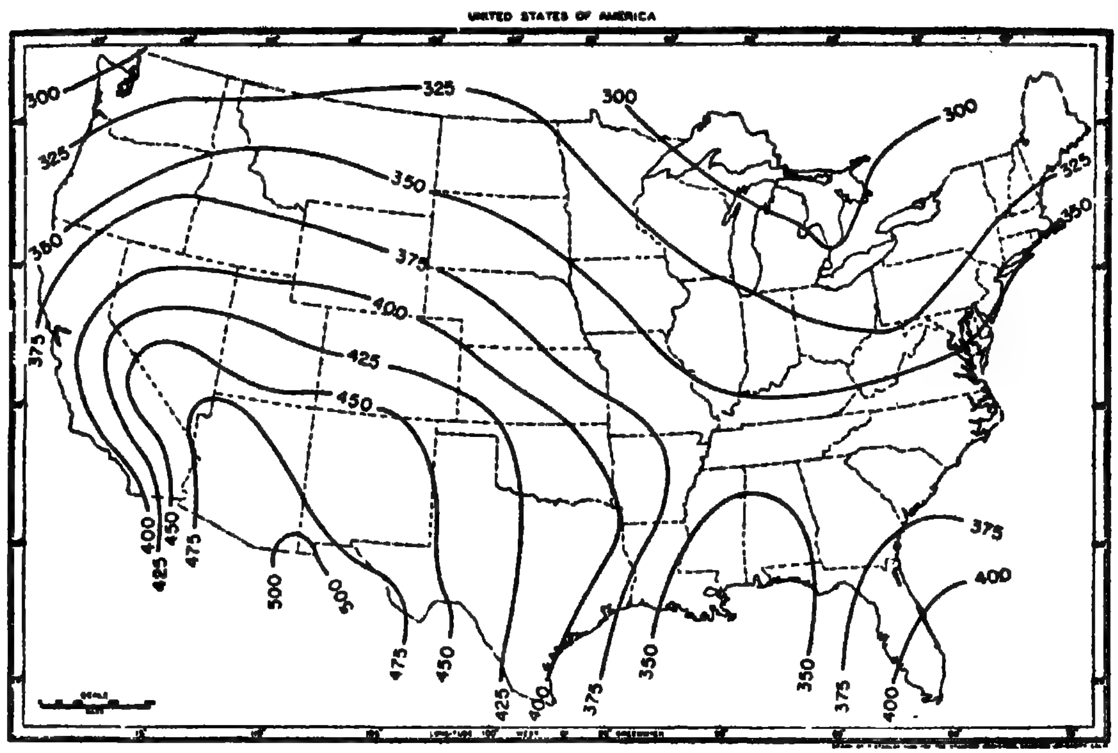


FIG. 7.18 AVERAGE DAILY SOLAR RADIATION (LANGLEY) IN THE UNITED STATES.

during the minute (in miles per hour) is obtained. At many airports the only record is that of the hourly one-minute average velocity. The same type of anemometer can be geared to contact after each mile and can be connected to a recorder that indicates the time of each contact. The speed between contacts is determined by measuring the time interval.

A more recent development in anemometers is the propeller type, in which a two- or three-bladed propeller rotates about a horizontal axis. A tail vane keeps the rotor pointing into the wind. An armature is rotated inside a coil by the propeller and the current generated varies with the speed. A dial microammeter shows the instantaneous wind speed, or a recording ammeter can provide a continuous trace. This type of anemometer makes possible a better estimate of gust velocities, but the inertia of the assembly considerably dampens wind-speed fluctuations of very short periods.

A pressure tube anemometer consists of a pitot tube mounted with a tail vane to keep it pointed into the wind. Pressure variations are transmitted to a recording device, often a pen floating in a mercury manometer. The pressure tube anemometer gives the most detailed record of wind-speed fluctuations if the manometer is sufficiently sensitive.

11.2 OBSERVATIONS OF WIND DIRECTION

Wind direction is observed with a wind vane. Most airport stations read the direction at hourly intervals from a direct-reading dial positioned by a selsyn transmitter at the vane. Some offices record direction each minute to eight compass points by means of an arm attached to the vane which contacts one of four directional segments. A clock-driven switch is closed at one-minute intervals, causing one of four pens to mark on a sheet depending on the momentary wind direction. Intermediate directions are recorded when the contact arm bridges between two seg-

ments and causes two pens to mark simultaneously. Hourly *prevailing wind direction* is determined from the chart as the direction with the largest number of contacts during the hour. Daily prevailing direction is that direction with the largest number of hours prevailing. Note that prevailing direction is only the direction that occurred most frequently and may actually have occurred as little as 20 per cent of the time.

11.3 VARIATIONS IN WIND

Wind is probably the most variable element of climate in terms of point-to-point differences. Local surface winds are greatly influenced by topography, vegetation, and structures. Obstruction by buildings usually results in lower wind velocities in cities than in the surrounding country (Art. 7.1). Valleys receive the same sort of shelter from surrounding hills. In open terrane with little relief, wind data are usually transposable from the anemometer location to a wide surrounding area. In mountains, wind velocity and direction may vary widely over very short distances. Local observations are the only sure check on such variations.

Since wind is fluid (air) in motion, its speed is greatly affected by friction with the earth's surface. The effect of friction is evident up to altitudes of about 2,000 feet above the ground, but is most marked immediately above the surface. Height of anemometer is therefore an important factor in interpreting wind data. The relation between wind speeds at different levels in the friction layer is given approximately by the equation

$$\frac{v_w}{v_{w0}} = \left(\frac{Z}{Z_0}\right)^k \qquad (2)$$

where v_w is the wind speed and Z is height. The subscript 0 indicates the measured wind-speed and anemometer elevation. The exponent k varies from $\frac{1}{2}$ for winds under eight miles per hour to $\frac{1}{7}$ for winds over 35 miles per hour, with an average of about $\frac{1}{5}$.

11.4 HURRICANES AND TORNADOES

Hurricanes reach maximum intensity over the oceans and dissipate rapidly as they move inland. Coastal wind data in hurricane areas should not be transposed more than a few miles inland. Tornadoes encompass such a small area and are so violent that no measurements of velocity are availble. From the climatological viewpoint, tornadoes are treated as separate from the regular wind regime. Figure 7.19 shows tornado probabilities by states for the United States.

12. HUMIDITY

12.1 OBSERVATIONS

Since the moisture content of the air must be measured indirectly, it is one of the most difficult elements to measure. Most observations are made with *psychrometers* consisting of a pair of thermometers, one of which has its bulb covered with a muslin wick moistened with water. When these thermometers are ventilated by whirling or by use of a fan, evaporation from the moistened wick depresses the wet-bulb temperature. An empirical correlation between the dry-bulb temperature and wet-bulb depression permits calculation of dew point or relative humidity.* Thermistors or thermocouples are sometimes used as elements in continuously recording psychrometers.

A more common humidity recording device is the *hygrograph,* in which the variations in length of a strand of human hair actuate a pen which records relative humidity. Records from hygrographs may often be substantially in error.†

* *Psychrometric Tables* (Washington, D. C.: U. S. Weather Bureau, 1941).

† M. F. Mueller, "Characteristics of Hair-element Humidity Instruments," *Instrumentation,* Vol. 22, September 1949, 798-799; and N. Sissenwine, "On Inaccuracies of the Hair Hygrograph Operated in Closed Tents," *Bulletin of the American Meteorological Society,* Vol. 28, April 1947, 192-196.

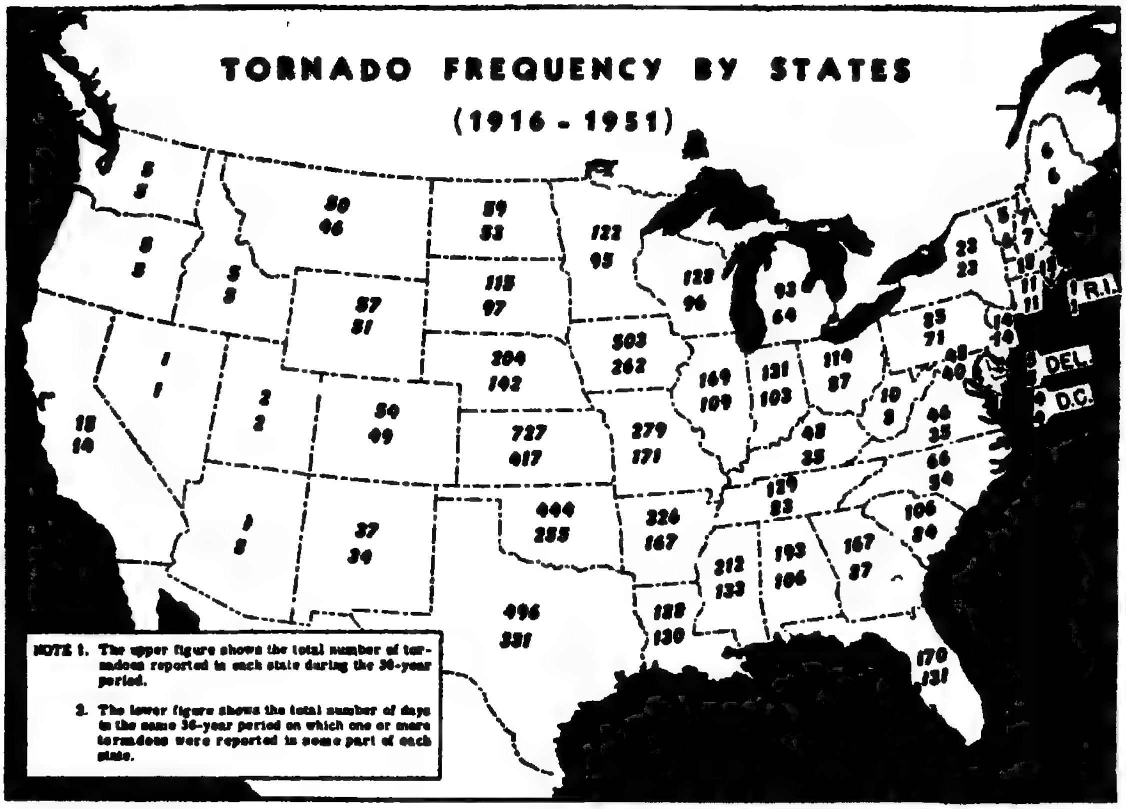


FIG. 7.19 TORNADO PROBABILITIES IN THE UNITED STATES (U. S. WEATHER BUREAU).

The hairs are affected by temperature and show a lag that increases with decreasing temperature, becoming almost infinite at −40° F. Frequent exposure of the hair element to a wide range in humidity is necessary for good results. Continued exposure in a very dry or wet atmosphere may cause a drift in the instrument calibration. Records from hair hygrographs should be adjusted to conform to psychrometer observations near the daily maximum and minimum humidities.

12.2 UNITS OF HUMIDITY

Vapor pressure is the partial pressure exerted by water vapor in the air. It is most commonly expressed in millibars (1,000 dynes per square centimeter) and is computed from an empirical equation using wet- and dry-bulb temperatures and air pressure. The *dew-point temperature* is the temperature at which a given parcel of air would become saturated with water when cooled at constant pressure without change in moisture content. *Absolute humidity* is an expression of the mass of water vapor in a given space. It may be computed from the equation

$$a_h = 217 \frac{e}{T_a} \tag{3}$$

where a_h is absolute humidity in grams per cubic meter, e is the vapor pressure, and T_a is the absolute temperature in ° K (zero = −273° C).

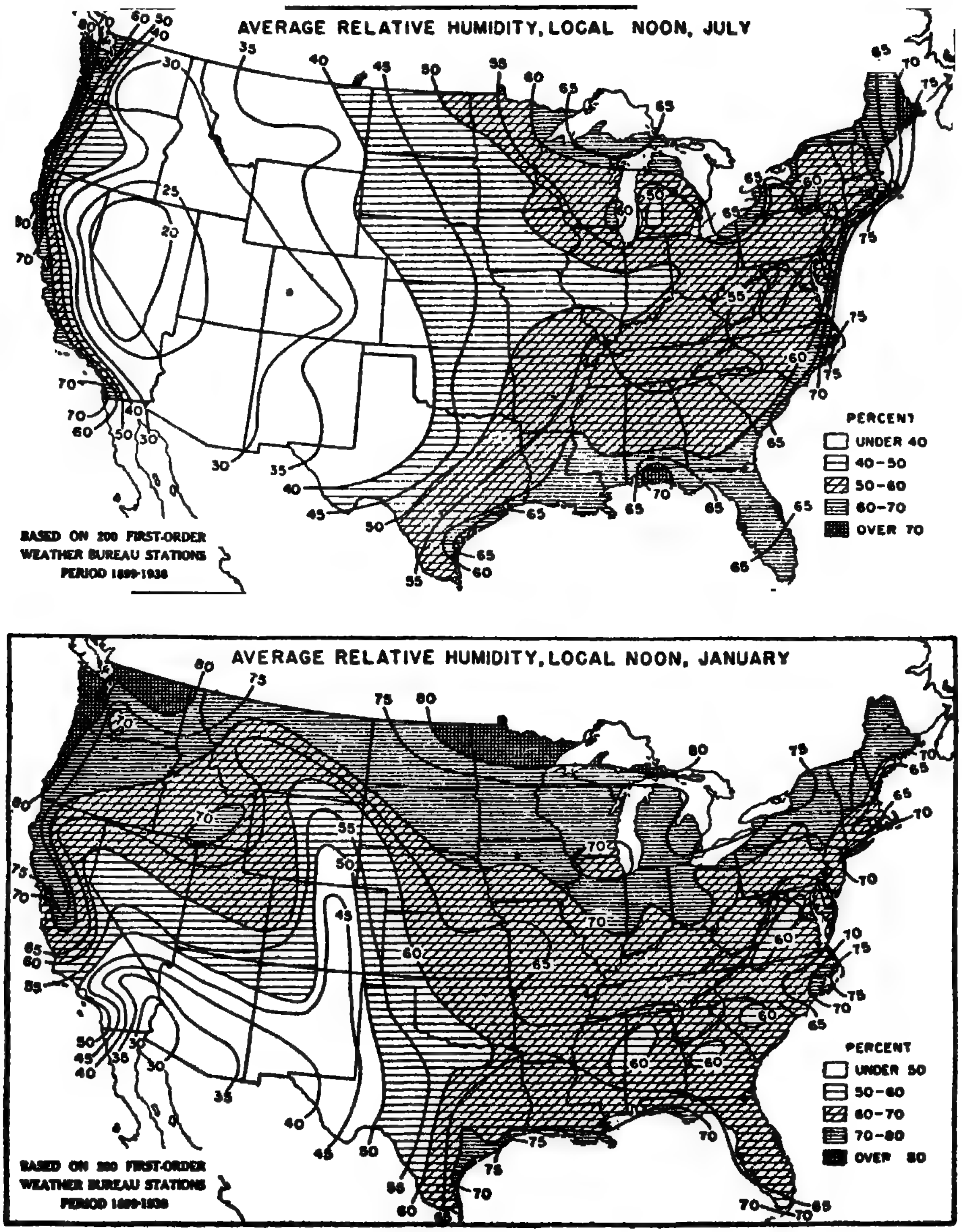
Relative humidity is the percentage ratio of the moisture in a given space to that which the space could hold if saturated. It is given by the equation

$$f = 100 \frac{e}{e_s} \tag{4}$$

where f is relative humidity in per cent, e is vapor pressure, and e_s is saturation vapor pressure. Relative humidity is widely used because it reflects the effect of humidity on human comfort, but it is

an unsatisfactory measure for many purposes because it is a function of temperature. With a constant moisture content, relative humidity rises as air temperature falls, and vice versa. The other expressions for humidity remain constant unless there is an actual change in the moisture content of the air. Relative humidity data show a marked diurnal variation, while the other measures of humidity vary only slightly throughout the day.

FIG. 7.20 AVERAGE RELATIVE HUMIDITY AT LOCAL NOON (PER CENT) FOR THE UNITED STATES (U. S. WEATHER BUREAU).



12.3 VARIATIONS OF HUMIDITY

In contrast to the elements discussed in the previous sections, humidity is a relatively stable element. Dew-point temperature, vapor pressure, and absolute humidity are usually about the same over a fairly large area and their normal values are similar for large areas. Since relative humidity is a function of temperature, it is more variable because of the temperature differences imposed on the humidity differences.

In general, humidity is a function of distance from a source of moisture; it is maximum along coastlines and minimum in the interior of continents (Fig. 7.20). Since the maximum quantity of vapor the air can hold is a function of temperature, absolute humidity is greatest in the low latitudes. Dew-point temperature cannot exceed the temperature of the source of atmospheric moisture. Hence coastal dew points approximate the temperature of the adjacent ocean waters. The maps of Fig. 7.10 show relative humidity at noon (local time). Since this is near the daily temperature maximum, relative humidity is near the diurnal minimum. The two maps also show a marked seasonal variation in humidity in the interior of the country but relatively little seasonal difference along the coast.

13. STATISTICAL METHODS IN CLIMATOLOGY

13.1 FREQUENCY DISTRIBUTIONS

Climatological analysis depends heavily on basic statistical methods. The climatologist's special role in an analysis lies in his understanding of the limitations of the data and the interrelations that may be expected. Methods of statistical analysis in climatology are discussed at some length by Conrad and Pollak.* Since climatology is concerned mainly with probability, the character of the frequency distributions encountered becomes important. With a large number of data, the events with moderately high probability can be predicted quite accurately from the raw data. If the data are limited in number or if interest centers on events of low probability, the results may be considerably enhanced by using a suitable theoretical distribution. A tentative estimate of the length of record required to obtain a stable frequency distribution for various elements and types of climate is shown in Table 7.3.

Climatologists have commonly assumed that the normal distribution is applicable to most climatological data. The adequacy of this assumption depends on the problem at hand. The distributions of several elements for Washington, D. C. are shown in Fig. 7.21. The smoothed curves are the normal distribution as fitted to the data. Monthly and annual means of temperature, wind speed, sunshine, and humidity conform to the assumption of normality. Precipitation for months or years is usually slightly skewed, but often it can be satisfactorily treated with the normal distribution in problems not concerned with extreme values. The distribution of short-period values of almost all elements departs from the normal more

* See bibliography at the end of this section.

TABLE 7.3 APPROXIMATE LENGTH OF RECORD IN YEARS REQUIRED FOR A STABLE FREQUENCY DISTRIBUTION*

	Type of area			
Climatic element	*Islands*	*Coasts*	*Plains*	*Mountains*
Temperature	10	15	15	25
Humidity	3	6	5	10
Cloudiness	4	4	8	12
Visibility	5	5	5	8
Precipitation amounts	25	30	40	50

* *Study of Length of Record Needed to Obtain Satisfactory Climatic Summaries for Various Meteorological Elements* (Washington, D. C.; Army Air Forces Weather Information Branch Report 588, November 1943).

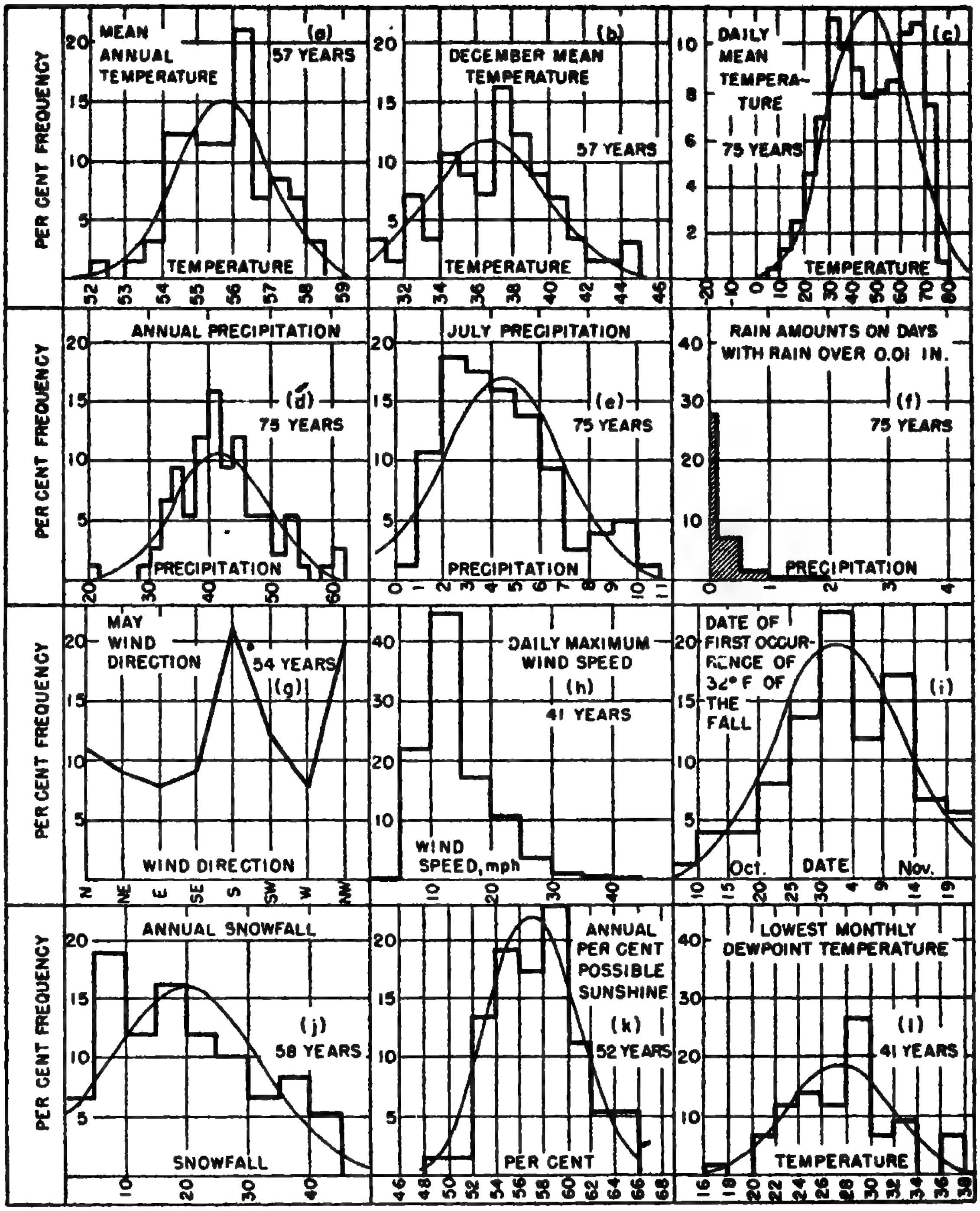


FIG. **7.21** SOME FREQUENCY DISTRIBUTIONS OF CLIMATIC ELEMENTS FOR WASHINGTON, D. C.

then does that for long-period measurements. Hourly wind speed in New England appears to conform to the Pearson Type III distribution.* Distributions of daily and hourly precipitation are highly skewed. Cloudiness and wind direction often show bimodal distributions.

* P. C. Putnam, *Power from the Wind* (New York: D. Van Nostrand Company, Inc., 1948).

13.2 EXTREMES

Many climatic elements are restricted within very definite limits. Percentage of sunshine, cloudiness, and

TABLE 7.4 PROBABILITY THAT AN EVENT OF GIVEN RETURN PERIOD WILL OCCUR WITHIN A SPECIFIED NUMBER OF YEARS

Period (years)	*1*	*10*	*50*	*100*	*500*
Return period (years)					
1	1.0	1.0	1.0	1.0	1.0
5	0.2	0.89	0.99999		
50	0.02	0.18	0.64	0.87	0.99996
100	0.01	0.10	0.40	0.74	0.993

humidity can vary only between zero and 100 per cent. Wind speed and precipitation are limited by zero at the lower end of their range, but for practical purposes can be assumed to have no physical upper limit. Temperature can vary between absolute zero and the boiling point, but actual temperatures are within such a limited portion of this range that temperature may be considered an unlimited variate.

For factors that can be considered as unlimited, the most satisfactory treatment of extreme values seems to be in the theory of extreme values.* The theory applies to a series made up from the extreme values of a group of series such as annual temperature maxima, annual precipitation maxima, and so forth. Analysis of extreme values of the annual total or average of a weather element is probably accomplished as well by the use of the normal frequency curve as by any other method. The annual averages of the limited factors such as percentage of sunshine vary so little that they can be considered unlimited variables in most cases (Fig. 7.21k).

Actually, there is no theory that can provide a reliable estimate of the return period for the maximum value of a series. If the true return period of an event is T years, the probability that it will occur in any year is $1/T$. From the principles of probability, the probability that an event that equals or exceeds the T-year event will occur in any series of n years is $1-(1-P)^n$ where $P=1/T$. Table 7.4, which is computed from this expression, shows the probability that events of various return periods will be observed in a given interval of years. The table indicates, for example, that there is one chance in ten that the highest event in a ten-year period actually has a true return period of 100 years. However, there remains a slight probability (seven chances in 1,000) that the largest event in 500 years is only the 100-year event. The use of a theoretical distribution as an aid in extrapolating frequency curves permits the inclusion of the lesser events whose return periods are better established, and reduces the likelihood that the extremes will be given excessive weight in the extrapolation.

* R. A. Fisher and L. H. C. Tippett, "Limiting Forms of the Frequency Distribution of the Largest or Smallest Member of a Sample," *Proceedings of the Cambridge Philosophical Society*, Vol. 24, 1928, 180-190; and E. J. Gumbel, "On the Frequency Distribution of Extreme Values in Meteorological Data," *Bulletin of the American Meteorological Society*, Vol. 23, May 1942, 95-105.

14. STATEMENT OF THE CLIMATOLOGICAL PROBLEM

The first step in the solution of a climatological problem is the rigorous statement of the conditions of the problem. Such a statement must come from a person who is intimately familiar with the application. Otherwise, an erroneous solution may develop. Aircraft spraying of insecticides is best accomplished under conditions of minimum air turbulence so that the dust will settle rapidly in the desired area. Although spraying of fungicides might seem to offer a similar problem, it is actually necessary to have a slight amount of turbulence in order that the fungicide will reach the bottom as well as the top of the plants.

In stating his problem, the industrial user of weather data must be prepared to

TABLE 7.5 QUESTIONNAIRE FOR PLANNING CLIMATOLOGICAL ANALYSIS*

1. Where will the operation take place?
   a. At specified point or points?
   b. Anywhere within an area limited by geographical, topographic, or economic factors?
   c. Can a favorable location be selected?
2. When will the operation occur?
   a. Is the operation to be continuous?
   b. Will operations be limited to a specific clock hour, season, month, etc.?
   c. Can a favorable operation time be selected?
3. What efficiency is required?
   a. Is operation required under all possible conditions?
   b. Is a calculated risk of inoperativeness acceptable?
      (1) Will the limitations on operation be on an areal, time, or economic basis?
4. What weather factors are involved?
   a. Specifically how does each factor or combination of factors affect the proposed operation?

* Adapted from W. C. Jacobs and W. C. Spreen, *Some Climatological Problems Associated with the Assignment of Engineering Design Criteria* (Chicago: American Meteorological Society, September 11, 1952).

answer a questionnaire essentially like that shown in Table 7.5. The answers to this questionnaire define the area of interest, the controlling weather parameters and their tolerable limits, the operational efficiency required, and the time of the operations. Although some of this information is unimportant in specific cases, in general each item of information plays an important role in securing the correct solution. The design of searchlight cooling equipment would ordinarily be based on nighttime temperatures only, unless it is specified that the light may be used during the day. If an operational efficiency of 100 per cent is required, the climatologist searches for the probable upper limit of the controlling parameters. If an alternate location is permissible, a high efficiency may be obtained by planning operations at one site when the conditions are unfavorable in another location.

The exact answer to Item 4, Table 7.5, may be difficult to state because the effect of the weather factors is imperfectly understood. Deterioration of materials is a function of several weather factors, but until the nature of this function is determined experimentally, it is difficult for the climatologist to be helpful. An empirical equation for deterioration has been suggested * as follows:

$$A = ax^t + b\frac{(f-K)}{100}(1.054)^t(1 + cI)(1 + 0.067w)$$

where A is the deterioration rate, t is the temperature of the deteriorating surface, f is relative humidity, I is the concentration of effective impurities in the air, and a, b, c, x, and K are experimental constants. Such an equation defines precisely the weather factors of the problem. Although an equation of this type is not essential, simple least-squares correlation or analysis of variance may be helpful in selecting the important weather parameters.

15. SITE TESTING

It is fortunate when a climatological problem develops for a point where a climatological station exists. But in most cases the problem involves a point at which no data have been collected. Transposition of record from a nearby station or interpolation between existing stations may prove satisfactory, but in many cases the accuracy of the

* C. E. P. Brooks, "Climate and the Deterioration of Material," *Quarterly Journal of the Royal Meteorological Society*, Vol. 72, 1946, 87-92.

analysis is materially improved by the collection of data at the actual site. If three or more years of record are collected, the techniques described in Arts. 8.4 and 9.5 will be helpful, but even a short period of record interpreted by a meteorologist in the light of the physical setting can be very useful. Very little research has been conducted to determine the length of record required to make the reduction of a short record to a long record possible. Putnam* found that for analysis of hourly wind data in connection with wind-power studies a record of ten days was adequate to estimate probable wind frequency at a site ten miles from an established station, and 90 days at a site 38 miles from an existing station.

* *Power from the Wind.*

Obviously, the most desirable situation is that in which the necessary supplemental station is established as soon as the existence of a weather problem is recognized. The cost of instruments and operation may easily be less than $1,000 for the first year, a cost almost certain to be negligible in comparison with project costs. In many cases, the instruments can be re-used at other sites as subsequent weather problems develop.

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In 1941, he returned to V. P. I. as an Instructor in industrial engineering. He advanced through the ranks of assistant and associate professorships and became acting professor and acting head of the department in 1947.

Mr. Ireson has specialized in the production aspects of industrial engineering, especially in production planning and control, factory planning, and statistical quality control. He has written one textbook, *Factory Planning and Plant Layout*, and numerous articles and papers on teaching methods, production planning, quality control, engineering economy, and work simplification.

He is a registered professional engineer in Illinois and has done consulting work with a number of companies and organizations. He has been guest lecturer at the University of Alabama and the School for Workers of the University of Wisconsin. He is a member of American Society of Mechanical Engineers, American Institute of Industrial Engineers, American Society for Engineering Education (Chairman of the Industrial Engineering Division, 1952-1953), and the American Society for Quality Control.

SECTION 8

Factory Planning and Materials Handling*

William Grant Ireson

1. TERMINOLOGY

Most of the terms employed in discussing factory planning and materials handling will be defined at the most appropriate point throughout this section. A few terms are used so frequently, however, that it is appropriate to define them at this point.

Factory: Any place in which the factors of production, land, labor, capital, and enterprise, are brought together for the creation of goods or services. The term *plant* is used synonymously with factory throughout this section.

Factory Planning: The formulation of a complete plan for the creation of goods or services. The term embraces the determination of the location, production processes, equipment, physical arrangement, provisions for personnel, offices, and all functions that are necessary to the completion of the goods. It implies that a careful study has been made of the several alternatives at each phase of the process and that the course has been adopted that has the greatest likelihood

* Some of the material in this section is reproduced from William Grant Ireson, *Factory Planning and Plant Layout* (New York: Prentice-Hall, Inc., 1952). A substantial part of this section has been rewritten by the author from the same source.

of providing the required service most economically, considering the long run.

Plant Layout: The analysis and proposal for the physical arrangement of the physical facilities after the decision on the site, production processes, and equipment has been made. This is a more restricted term than factory planning. It is not limited to the process of determining the arrangement of a given number of machines within a department by means of templates or models, as is often erroneously believed.

Continuous Industry: An industry in which it is impossible to stop the production process on short notice without suffering considerable loss in partially processed materials, in damage to equipment, or in labor and materials required to clean out and recondition production equipment. This classification is useful in factory planning because the continuous industry's problems of factory planning are very different from those of the interruptible industry.

Interruptible Industry: An industry in which the production process may be stopped on short notice without suffering any losses except those caused by idleness on the part of the workers and the equipment. Many factories of the interruptible type do operate on a twenty-four hour basis, seven days a week. Continuous industries have to work on this basis and take great precautions against breakdowns that might cause a rapid shut-down of the processes. A great many plants have both continuous and interruptible processes or divisions.

2. INTRODUCTION TO FACTORY PLANNING

2.1 THE WHOLE PROBLEM

A factory is a complex unit that directly and indirectly affects the lives and well-being of many persons. Its existence is justified by the fact that the goods or services produced satisfy needs or desires for which money, or some other medium of exchange, is sacrificed. The more economically the goods or services can be produced, the greater the number of persons who may enjoy the benefits of the products. The opportunity to satisfy these needs and desires at a profit provides the incentive for the entrepreneur to risk his time, effort, and capital in the development of a factory.

The selection and arrangement of the physical facilities that constitute the factory, and the provisions for the comfort, safety, and efficiency of the persons who work in it are extremely important to its economical operation. Every elementary activity that occurs in the production of goods or services takes place in reference to physical items: materials, machines, desks, conveyors, light, heat, tools, workmen, foremen, time clocks, washrooms, and on and on, ad infinitum. It is obvious, then, that each of these items constitutes a source of variation in the over-all plan. It may be assumed that there is an optimum selection and arrangement of these items for most economical production. The objective of factory planning is to find, as nearly as possible, this optimum combination of all the variables.

In reality, the problem of factory planning consists of many separate and semi-independent problems. This fact greatly simplifies what otherwise would be an almost insoluble problem, for each separate problem can be identified and the factors that affect it can be determined. By making use of all possible methods of analysis and synthesis, the one best solution for the given conditions can be determined with reasonable facility. Interdependence among the separate problems can be considered, and the solutions of the separate problems can be tempered to obtain the over-all optimum solution for the entire factory.

Items that are variable in one problem may be fixed in another. It is important, then, to recognize and separate the variable factors from the fixed factors in each instance, so that the degrees of variation of variable factors will be considered only within the limits permitted by the fixed factors. For instance, planning the production facilities for a

new product within an existing building and with existing tools and equipment involves considerably fewer variable factors than planning for the same product in a new building (yet unbuilt) with new equipment (not yet selected). In the existing building, the permissible floor load, column spacing, placement of stairs, elevators, and walls, and ceiling or working heights establish the physical limits within which the production facilities must be planned. Existing machines, tools, equipment, and designs fix the output capacities, space requirements, sequence of operations, and many other factors. The result is that the factory planner has fewer variables with which to work and less freedom in which to vary the remaining factors than he would have if no building or equipment existed.

The development of a systematic procedure for the collection and analysis of data and the formulation of the best possible plan is the objective of this section. Briefly, the procedure is:

1. Collect all factual data regarding the products, volumes, markets, facilities, financial resources, forecasts of future developments, labor supply, management policies, competition, and so on.

2. Separate the fixed factors from the variable factors and establish quantitative values, wherever possible, for each factor.

3. Working from the fixed factors, establish the practicable limits of variation for each variable factor and determine the results of allowing the variable factors to assume the different possible values.

4. Analyze the combined effects of selecting the value for each factor which will maximize the productivity and/or minimize costs.

5. Choose the combination that provides the optimum solution to the problem.

2.2 MANAGEMENT'S INTEREST IN FACTORY PLANNING

In most businesses, competition for the available market constantly forces the management of each concern to seek competitive advantages through such methods as:

1. Product improvement or new products.

2. Lower costs and lower selling prices for the same or better quality.

3. Better service to customers.

The selection and arrangement of physical facilities (the factory plan) can assist in achieving these advantages and the re-layout of facilities can frequently lead to relatively large annual savings. Some of the ways in which the factory plan can effect economies in operation are:

1. Lower labor costs, both direct and indirect.

2. Reduction in work stoppages and down times; fewer interruptions of production.

3. Reduction in the cycle time required for production.

4. Reductions in the inventories of work-in-process, raw materials, and supplies.

5. Greater production capacity without additional equipment, space, or employees.

6. Simplification of production and material controls.

7. Increased flexibility in the output, in terms of both the volume and the variety of products or services.

8. Lower materials-handling costs.

9. Lower plant-maintenance and engineering costs.

10. Lower storage costs.

11. Provision for later expansion or contraction at a minimum cost and minimum interruption of production.

12. Greater ease in effecting changes in layout.

13. Better morale and lower turnover among employees.

14. Reductions in employment and training costs.

15. Faster service to customers.

16. Fewer problems that require managerial attention as a result of better production facilities and better employee relations.

The opportunities for these economies are not always evident to top management. It becomes the duty of the lower

levels of management, which are closer to the problems, to be alert to the possibilities. Article 2.6 gives a list of conditions that indicate the need for embarking on a factory-planning analysis.

2.3 THE ORGANIZATION FOR FACTORY PLANNING

The factory-planning function is essentially a staff function, but current practice does not provide any real precedent for its inclusion in the organization chart as a separate functional group. Large and small industrial concerns vary considerably in their treatment of the planning function. Some assign it to the plant engineering group, some to the methods department, others to the production planning department, and still others to a separate department that may be in charge of factory planning, plant layout, materials handling, and other functions. In some concerns, the factory-planning group is a planning group only, leaving the execution of the plan to other divisions, such as plant engineering; in other concerns, the planning group is responsible for both the planning and the execution of the plan, for the installation of equipment, and for the establishment of production procedures and standards. Each organization must determine which plan of organization is best suited to the personalities involved, the abilities of the persons available, the availability of information to certain groups and not to others, and the existing division of functions.

Regardless of the place of the factory-planning group in the organizational chart, the group must have access to information on the volume of output of the several products, proposed changes in methods of production; product designs; sales promotion programs; availability of labor; labor rates; cost data on the past performance of materials handling, labor, and machines; and availability of funds. Since this information must come from a large number of different sources, it seems logical that a separate department, armed with authority to request the information, should be established to carry out the planning function. The very fact that such diverse kinds of information must be used in arriving at an economical plan for the plant indicates that a separate department should be responsible for handling it.

Another reason for having a separate department is that the planning group should be free from the influence that might be exerted by its parent division.

There is ample evidence that the planning function should be set up as a staff function possessing the authority to obtain necessary information from all departments, and that it should be responsible for making complete plans, including performance schedules, to be executed by the other departments. Such an organization does not relieve the planning department of the necessity for maintaining a cooperative and congenial working relationship with the other departments. It should consult with all interested groups and departments while it prepares plans and schedules of execution, so that the best interests of the company will be recognized and maintained.

In the smaller companies, where valid reasons exist for combining functions, certain plant activities might be combined into one department called the "Production Engineering Department." Such a department might be charged with the following functions:

Plant engineering
Production planning and control
Methods engineering
Production and wage standards
Plant engineering

The interrelationships among these functions are so great and important that there should be no conflict of interests; they are so closely related that the people in this one department can easily be shifted back and forth among the various activities to compensate for variations in the amount of work being handled by each.

In continuous industries, the plan for a new plant is usually completed in great

detail before construction begins. Once in operation, the continuous plant is usually not subject to further planning for several years. Large industrial concerns, which more or less continuously expand by building new plants or additions, usually maintain a staff of specialists in that particular type of industry. These specialists constantly search for new and better ways of producing the product and are responsible for planning the new plants, additions, and revisions. A smaller concern usually relies upon consultants and architects to design and plan its facilities, since it does not have a uniform and continuous need for the service (see Art. 2.7).

2.4 COST ANALYSIS OF FACTORY PLANNING AND LAYOUT

The final criterion for the effectiveness of the factory plan is the cost of the finished product, ready for sale. Every factor, fixed or variable, affects the final costs of producing the product, but it cannot be assumed that the degree of each variable factor that renders the lowest unit cost for that particular element of cost is necessarily the degree that should be chosen. The interrelation of cost items is such that frequently the selection of the most economical alternative for one factor will automatically preclude the selection of the most economical alternative for another factor. In other words, the most economical alternatives of two or more factors (when considered individually) may not be compatible when considered together relative to a particular problem. This is the reason that it is necessary, if the optimum plan is to be made, to have complete information regarding the costs of each degree or alternative for each factor in the problem. This information, and the knowledge of which alternatives will work together, make it possible to select the optimum combination.

2.4.1 Variables approach. All factory planning is done for the *future*. The basis for most factory planning is the estimates of future production demands for the products, and the estimates of future costs of labor, materials, machines, tools, and so on. Actual events are not likely to occur just as expected or estimated, however. Thus, it becomes increasingly important, as the uncertainty of the estimates increases, to consider probable variation from the estimates and to compute the effects of this probable variation on the final costs or on the costs of each element. The easiest way to handle this probable variation is to estimate probable maximum and minimum values for each factor. Then each cost item can be computed on the basis of both the maximum and minimum values as well as on the expected value. Analysis of the factor relative to changes in economic level, wage rates, public taxation, competition, military situations, employment, and population growth will indicate how the factor will react with each change. Then, assuming that certain changes may occur, either upward or downward, the effects on each cost factor can be estimated and the appropriate maximum or minimum value can be used in calculating the final total cost.

It is important to note that a given change from the expected in the future will cause some variables to be maximized and some to be minimized. The estimate of the total final costs, then, will not be made up of either the total of all the maximum cost estimates or the total of all the minimum cost estimates. Instead, it will be a mixture. The difference between the probable maximum cost and the probable minimum cost is not likely to be as great as the variation of individual factors indicates, for there are many compensating factors. Figure 8.1 is a simple illustration of the use of this concept.

All estimates of future expenses and incomes will be in error to some extent. The error cannot be predicted exactly, but it is reasonable to assume that future changes will similarly affect all estimates of the future, provided the same bases are used in making the original estimates. For example, the dollars-and-cents estimates of labor costs in the fu-

ANALYSIS SHEET

Product *Thermostat bracket* Part No. *B-475*

Department *Press* Analyst *KCB*

Present Method *3 Separate compound dies on 3 10 ton presses. Strip stock.*

Proposed Method *Multistage progressive die on one 30-ton press. Automatic feed using coiled strip stock*

Purpose of Proposal *Reduce labor costs (No change in overhead costs)*

Cost Factors	Present	Proposed Min.	Proposed Expected	Proposed Max. *
Annual Production (Units)		*30,000*	*50,000*	*75,000*
Die Cost ($)		*6,000*	*8,000*	*10,000*
Die Life (Units)		*100,000*	*200,000*	*300,000*
Labor Cost/unit (Including setups)	*$0.120*	*.01*	*.03*	*.05*
Material Cost/unit ($)	*.005*	*.006*	*.008*	*.009*
Cost Analysis		**Best Possible**	**Expected**	**Worst Possible**
Annual Production (units) *Die Cost ($)*		*75,000* *6,000*	*50,000* *8,000*	*30,000* *10,000*
Die Life (units) *Die Life (Years)*		*300,000* *4*	*200,000* *4*	*100,000* *3*
Equivalent Annual Die Cost (including 10% int.)		*$1893*	*$2524*	*$4021*
Unit Die Cost ($)	*0.0120*	*0.0252*	*0.0505*	*0.1340*
Unit Labor Cost ($)	*0.1200*	*0.0100*	*0.0300*	*0.0500*
Unit Material Cost ($)	*0.0050*	*0.0060*	*0.0080*	*0.0090*
Total Unit Cost ($)	*$0.1370*	*$0.0412*	*$0.0885*	*$0.1930*

*Probability of Estimate being exceeded: Min· *90*; Expected: *50*; Max: *10*.

FIG. **8.1** ILLUSTRATION OF CONCEPT OF PLANNING BY MINIMUM, EXPECTED, AND MAXIMUM VALUES.

ture for the several alternatives may be greatly in error, but the percentage difference in labor costs for the alternatives will not be seriously in error. This concept makes possible a reliable selection from the available alternatives.

2.4.2 Engineering economy approach. Many of the problems of factory planning are direct applications of the principles of engineering economy. Since an overwhelming portion of factory planning is the replanning of existing facilities and involves only one segment of a larger plant, the whole plan may be developed as a succession of small and relatively independent problems. In such cases, it is usual to find that a fairly limited number of practicable alternative solutions exists. The selection of one of the alternative solutions can be made by making a direct comparison of the alternatives by one of the engineering economy methods: rate of return on investment, equivalent annual cost, present worth, break-even point, capitalized cost, or time required for the alternative to pay for itself. Section 3, Arts. 2-7, describes these methods completely.

The engineering economy methods are directly applicable to the following types of problems:

1. The selection of plant sites.
2. The determination of the types of buildings and the number of floors in each.
3. The selection of machinery and production equipment.
4. The selection of materials-handling systems and equipment.
5. The arrangement of the producing departments within the buildings.
6. The provision of factory services (immediate capacity and distribution of steam, gas, air, power, etc.).
7. The determination of the economic lot sizes to be produced.

2.5 PLANNING FOR THE FUTURE

Each factory-planning problem must be considered from two viewpoints: immediate needs and future needs. The less stabilized the industry is, the more important it becomes to plan for future eventualities. Such factors as public acceptance of the product, rate of development of competing lines, financial conditions, amount of current research and development on the product, age of the industry, and research and development of production methods largely determine the length of time over which the present arrangement can be expected to remain unchanged and economical. If this expected time is short, there is a great incentive to plan the factory so that future changes can be made quickly and economically to accommodate changing conditions. This condition is described as the flexibility of the plant. Most of the non-continuous industries must anticipate constantly changing conditions and must build this flexibility into the factory plan.

Flexibility is accomplished by providing in the original plans the following conditions:

1. Wide column spacing to permit freer arrangement of equipment.
2. High floor load capacities and structural strength.
3. Adequately high ceilings or clearances for handling equipment, dust-collection equipment, air ducts, and the like.
4. A network of exposed or conveniently enclosed service lines with frequent tap-offs: steam, gas, compressed air, electricity, water, etc.
5. Substantially larger capacity in service supply lines than immediately needed.
6. Standardized materials-handling systems that can be adapted readily to changes in size, weight, and nature of products.
7. Provisions for expansion of production facilities and/or buildings without interrupting existing layouts. Location of trunk lines so that additions will not require their relocation.
8. A long-range plan for growth by addition of buildings in the original plot plan.
9. Movable walls or partitions.
10. Adequate personnel facilities, strategically located.
11. Extra land for expansion.

2.6 CONSIDERATIONS THAT INDICATE NEED FOR FACTORY PLANNING

It usually is the responsibility of foremen, supervisors, and lower management personnel to bring to the attention of top management the need for embarking on a factory-planning project in existing plants. These persons are closer to the actual production problems and should be the first to realize that improvements can be made. Even the workmen see opportunities for improvement and should be encouraged to point out places or ways whereby the productivity of the plant can be increased. Frequent surveys by responsible persons can locate impending trouble before it occurs. The occurrence of any of the following conditions indicates that the factory plan should be studied for

the purpose of improving productivity at lower costs:

1. Changes in the product: new styling, new models.

2. Addition of new products and deletion of old ones.

3. Changes in the location or concentration of markets.

4. Changes in the volume of demand.

5. Worker complaints regarding working conditions (noise, light, temperature, etc.) (see Section 12, Art. 9).

6. Worker complaints on availability of materials, tools, instructions, etc.

7. Sudden increase in absenteeism (see Section 12, Art. 3).

8. Frequent accidents (see Section 11, Art. 1).

9. High labor turnover (see Section 4, Art. 5).

10. Large amount of, or increase in, idle machine time.

11. Frequent failure to meet promised delivery dates or production schedules (see Section 6).

12. Foremen's requests for additional equipment or workers.

13. Foremen's complaints about delays in supplies from other departments.

14. High or rapidly increasing maintenance on equipment and buildings (obsolescent facilities) (see Section 3, Art. 13).

15. High percentage of rejected product by inspectors or customers (see Section 14, Art. 6).

16. Increasing difficulty in finding suitable employees.

17. Congestion in plant, lack of storage space, shortage of trucks, skids, etc.

18. Higher in-process inventory than usual.

The existence of any one of these conditions means that some opportunity for improvement exists, and there is a reasonable likelihood that factory planning is involved. An investigation should be initiated and the problem should then be turned over to the group or groups involved for a complete investigation and recommendations. Every group that is directly affected or that directly contributes to the condition should be consulted and invited to participate in the investigation.

2.7 THE "WHEN" OF FACTORY PLANNING

As was indicated in the previous article, a factory-planning study should be initiated whenever a condition exists that offers opportunities for improvement of productivity, improved morale, or lower production costs. However, the effectiveness of such a plan, if used exclusively, would be largely accidental. The factory-planning program should be more systematically organized in order to be most effective. The functions of factory planning should be definitely provided for in the organization chart, even if they constitute only part of the duties and responsibilities of one person.

There are three basic methods of timing factory-planning activities: (1) accidental (described in Art. 2.6), (2) periodic, and (3) continuous or continuing.

2.7.1 Accidental programs. An "accidental" program usually results when someone close to the problem suggests that a problem exists. This method is haphazard and seldom can be relied upon to produce the desired results throughout the entire organization. Workers and foremen alike frequently hesitate to criticize existing conditions for fear of job security. What is everyone's responsibility is no one's responsibility, and conditions have to become acute before action is taken.

2.7.2 Periodic programs. The "periodic" method is most frequently employed by continuous industries or by industrial concerns that habitually change models periodically. In the continuous industry, simple changes in process arrangement are seldom possible. Great care must be exerted during the design stage and prior to construction to see that the plant embodies the most advanced thinking and knowledge so that it will have the greatest possibility of running economically for a long period of time. On the other hand, recent developments must be investigated periodically to find out if some new idea or equipment can be incorporated in the

plant and justified through prospective savings.

Industrial concerns that change models periodically customarily follow a definite schedule in replanning the factory for the new product. As each part or design is frozen, the factory-planning engineers proceed to determine methods, tooling, materials, and so on, in conjunction with the appropriate engineering groups. They then determine the arrangement that will work best and prepare instructions for the plant engineering group, millwrights, electricians, and plumbers, so that everything is in readiness for a rapid change-over to the new plan when production on the existing model is halted.

2.7.3 Continuing programs. The "continuing" method is employed by firms that employ a separate factory-planning group, and that do not systematically change models. A typical concern is one that manufactures several different lines of products along with a certain amount of custom or jobbing work. This method calls for a central group charged with the responsibility of constantly seeking ways to improve the plant arrangements. It provides for specialization of labor, a clearing house for all ideas and suggestions, a formalized procedure for the accumulation of data, the development of special skills, and, what is most important, a planned program of plant improvement. This last item means that no one segment of the plant will be overlooked and that the effort will be expended where it has the best possibility of securing the greatest results.

3. PLANT LOCATION

The problem of plant location exists whenever a plant expansion is contemplated. Presumably, there are always two or more alternatives open to the industrial concern. The first is not to expand, the second is to expand at the present location, and the successive alternatives are to expand at different locations. The nature of the alternative locations and the attractions and disadvantages of each are the determining factors in the final decision. The best location is one that will enable the company to produce and distribute its product with the greatest profit. It is commonly said that the best location is the one that permits the concern to produce and distribute its product (some assumed and fixed quantity) at the lowest over-all cost. This is not necessarily true, because the location of the plant relative to markets will, in many instances, directly affect the volume of the product that can be sold. The greater volume at one location, even though it may result in a slightly higher unit cost, may still render a greater profit.

The three elements of cost for location analysis are (1) cost of obtaining suitable raw materials and supplies, (2) cost of conversion or production of the product ready for sale and (3) cost of distributing the product to the dealer or consumer. Each of these cost elements will be affected by the location of the plant relative to the sources of raw materials and supplies, labor and equipment markets, and markets for the finished product. In the following discussion of determining factors, each element will be present but will not be discussed at length. A little thought on the matter will reveal how each factor affects these cost elements.

The problem of plant location consists of two major divisions: (1) the selection of the geographic region and (2) the specific site selection within the region.

3.1 REGIONAL SITE SELECTION

The factors and their effects on the total costs vary with the regions of the nation. Table 8.1 provides a check list of factors and examples of cost items that may be adversely affected by the region.

The information necessary to make a reliable estimate of the general costs for a given region is readily available. Comparative labor costs by cities and regions are available from the U. S. Department of Labor and other agencies.

TABLE 8.1 FACTORS AFFECTING THE SELECTION OF A REGIONAL PLANT SITE

Factor	For each alternative region, check the effects of:
Raw Material Supply	Length of haul from source to region. Freight rates on the commodity, both raw and finished. Ratios of weights and volumes of finished products to weights and volumes of raw materials. Labor supply and attractions or accommodations to induce migration of labor to source. Availability of water, fuel, power, etc., at source. Different sources of raw materials. (They may be widely separated.) Availability of adequate transportation facilities.
Labor Supply in Region	Adequacy of supply of desired type for an additional plant. Competition for the existing supply. Suitability of existing supply, by former work or training, for the intended type of work. Union organization and strength. Race relations. Dependability of the type of labor available, and aptitude for factory work, training, and upgrading.
Marketing	Market area to be served by the plant. Concentration of market and stability of demand. Extra warehousing and inventories required as a result of plant location. Freight rates to principal market areas. Transportation facilities available to market areas. Travel expense for salesmen and service personnel. Risks of delays and damage to goods in shipment (customer relations). Competition for the market and relative location of competitors' plants.
Factory Services	Adequacy of supply of power, water, fuel, etc., for present and prospective plant size. Availability of external plant services: sewage disposal system, repair and replacement parts, fire protection, public transportation for personnel, etc. Available supply of trained management personnel. Attractions of region (cultural, climatic, etc.) for professional management personnel.
Climatic Conditions	Cost of construction to withstand forces of nature: earthquakes, winds, snow, etc. Heating or air-conditioning costs for either personnel comfort or process control. Probability of absenteeism caused by weather. Probability of work stoppages or interruption of supply of raw materials by weather. Necessity for premium wages because of weather conditions. Cost of maintenance, deterioration of products or raw materials, and rapid depreciation resulting from climatic conditions.

TABLE 8.1 (*Continued*)

Factor	For each alternative region, check the effects of:
Laws and Codes	Laws limiting scope of work permitted. "Fair Employment Practices Acts." Extra costs for unemployment insurance, workman's compensation, retirement insurance, and similar benefits. Waste disposal, smoke abatement, and nuisance regulations. Local tax laws on real property, corporate income, money on deposit, etc. State, county, or city building codes, and safety and health regulations. Rulings of such bodies as the Interstate Commerce Commission, which may penalize certain types of industries in certain regions.

Factory Management and Maintenance frequently publishes surveys of wage rates. Freight rates by classes of commodities can be obtained by regions from almost any railroad, and most railroads maintain special departments for the purpose of supplying information on many different cost items to prospective customers. Local building contractors and contractor associations can provide information about construction costs, and published information is available from many trade journals. State and local chambers of commerce will provide data on state and local laws, ordinances, codes, and regulations. Most states and communities realize the advantages of broadening the tax base by inducing industrial expansion. City councils, chambers of commerce, railroads, and merchants are anxious to supply information, make contributions to desirable industries, and make tax concessions in order to attract companies. But herein lies a danger. Sometimes these immediate advantages appear to be more important than they really are in the long-run economy of the company, and the chosen site may ultimately prove to be a poor choice.

The industrial plant that is seeking a site today has much greater freedom than it has had in the past. Some of this freedom has come about as the result of technological advances, changes in worker attitudes, and labor legislation. Specifically, some of the developments that have increased the freedom of location are:

1. Improvements in transportation facilities and speed of service.
2. Reduction in wage differentials between regions.
3. Mobility of workers and management.
4. Increased leisure time for workers, which places more importance on recreational facilities, cultural advantages, etc.
5. Improvements in construction methods and designs for plant buildings, which make them less expensive to build.
6. Trend toward one-floor plans that require large land areas and freedom for expansion.
7. Availability of automobiles for almost all workers, making large parking facilities a necessity for most plants and making more plant sites convenient to labor supply.
8. Improvements in processing and machine designs that reduce the relative number of employees required for a given output.
9. Equalization of freight rates between regions.
10. Availability of economical air-conditioning equipment to counteract adverse climatic conditions for employees and processes.
11. Expansion of markets for almost all goods and services so that more plants are needed to meet the demands.

No plant site should be chosen without a careful investigation and economy study of all the factors involved. It is almost impossible for any plant management to select the most economical plant

site by guess. What appear to be relatively small differences in costs between regions frequently turn out to be highly significant in the total cost.

3.2 SITE SELECTION WITHIN THE REGION

After the region for the industrial plant has been chosen, there remains the matter of selecting the specific site for the plant. There usually are as many alternative sites within the region as there are alternative regions, and the problem is frequently just as complicated and difficult to solve. Many of the same factors that are considered in the choice of a region are again considered relative to specific sites, but there are also other factors.

3.2.1 City, suburban, or country. A city site is one within the corporate limits of a city, and associated with the site are such conditions as heavily concentrated population, high land values, complete regulation of activities, and limited space. The suburban site is one outside the corporate limits of a city (usually a reasonably large city), and may be within the corporate limits of a smaller town or village. The country site is one that is usually some distance from an established center of population. The choice among these is usually based upon an economy study of the effects of:

1. Land cost.
2. Availability of and cost of labor.
3. Availability and cost of suitable transportation facilities to the site for raw materials, finished product, and personnel.
4. Local ordinances, building codes, and restrictions.
5. Available power, fuel, water, and sewage disposal.
6. Union activities and strength in the area.
7. Climatic conditions.
8. Size of plant, immediately and in the future.
9. Local property taxes.
10. Nature of processes and hazards or nuisances produced.

Some of the conditions that tend to dictate the choice of a country location are:

1. A need for a large amount of land for eventual development.
2. A need to use processes that are normally considered objectionable within populated areas.
3. A need for large volumes of relatively pure water, which can be obtained from streams, wells, or springs.
4. A need for a favorable property tax.
5. A need for protection against sabotage or the observation of processes or output.

Suburban sites are chosen for such reasons as:

1. A need for reasonably large land areas not obtainable in the city, yet close to transportation and a large population center.
2. A desire to be free from the more strict building codes and restrictions normally found in cities.
3. A need for a large number of female employees, generally available in suburban areas because of a lack of other employment opportunities.
4. A desire to escape high taxes.
5. A desire to escape from highly unionized areas.
6. A desire to locate nearer markets, transportation facilities, or employees' homes.

The city location is frequently chosen for plants that require:

1. A large portion of employees to be highly skilled.
2. Rapid transportation or quick contact with customers or suppliers.
3. Relatively small total space, which can be contained in multi-story buildings.
4. A large variety of materials and supplies, but each in relatively small quantities.
5. Public utilities, city water, electricity, gas, sewage disposal, police and fire protection, etc., at reasonable rates. (The company may not be in a financial position to provide these facilities for its plant.)
6. The means of getting into production with the least possible investment

in land, buildings, etc. These facilities can more frequently be rented in a city.

Few industrial concerns are fortunate enough to find a naturally ideal plant site. The objective of site selection studies is to find a site that can be developed and from which the operations can be conducted at the lowest over-all costs in the long run. The investment in the development of a site can be amortized over a period of years along with the plant buildings. A site that requires a greater initial expenditure for development may prove to be more economical in the long run, because of consistent annual savings in other cost items, than what at first appears to be a more suitable site. An engineering economy study is a "must" for site selection. (See Section 3 for a complete discussion of these methods.)

3.3 SITE PLANNING

The utilization of the site and the plan by which the ultimate factory will be arranged on the available land will have an important effect on the long-run economy of the plant. For a new plant, the tentative plans for the physical facilities, including immediate and prospective floor area, number and types of buildings, eventual employment, flow of materials, and auxiliary facilities, will have been prepared for use in the site selection. (See Art. 5.1 on the sequence of events in planning a factory.) The selected site conditions will in turn usually necessitate certain adjustments in the general plans. The site will first be described by a map showing the location of the site relative to highways, railway lines, rail sidings, power, gas, water, and sewer lines, towns, and public transportation facilities, and any existing structures. A topographical map will be prepared to show the contours and elevations of all segments of the land area relative to the same items. Drawings will be made of all existing structures, showing building details, floors, floor loads, columns, piping, power circuits, walls, doors, windows, and so forth. Climatological data, wind velocities and directions, temperatures, rain and snow fall, humidity, sunshine and cloudiness, and probability of extremes of each factor by months or seasons, will be obtained. (See Section 7, Art. 5, 6, 14, and 15, for accepted practices and sources of information for these data.)

With this accumulation of information, the planning group is ready to study the site with particular reference to the general plan for the factory. The group will attempt to place the several buildings on the site in such a way that full advantage can be taken of the site characteristics and existing conditions. Some of the things that the planners will attempt to do are:

1. Locate buildings that are to be served by rail lines near existing, or extensions of existing, rail sidings.
2. Locate areas to be served by highway trucks near existing highways or streets.
3. Locate employee parking facilities near existing streets and convenient to work areas. Several parking areas may be required.
4. Arrange buildings, relative to each other, so that full advantage can be taken of the prevailing winds for ventilation or removal of unpleasant smoke or fumes, of sunlight for lighting and heating buildings (in winter), and of buildings to protect much-used outside traffic lanes from wind and rain.
5. Arrange building so that additions for expansion can be made later without disrupting production, and so that roads, rail, power, water, sewer, and steam lines will not have to be relocated.
6. Avoid unnecessary scattering of buildings that will increase materials-handling and other service costs.
7. Take advantage of any natural slopes of the terrain to accomplish drainage, waste and sewage disposal, and materials handling.
8. Locate sources of dirt, fumes, and obnoxious products to the leeward side of the site. (Site should have been chosen so that such products will not be blown over populated areas. Not to do so invites regulation and corrective action.)

9. Locate office buildings near main street to facilitate visitors' entrance and exit, and plant protection.

10. Isolate especially hazardous processes and reduce the danger that fire will spread from building to building.

11. Make use of sound, existing structures, if their use will not increase other operating costs by an amount that will equal the amortization of the most economical substitute structure.

12. Plan for attractive appearance of plant, landscaping, lighting, etc., so that public and employee relations will be good.

It can be seen that the actual site serves to limit, and at the same time may assist, the planning group in arriving at the optimum factory plan. Advantages that were not expected when the general plan was drawn up may appear, and, also, adverse conditions may be present that were not expected. In any event, once the site has been selected, the planning engineers have a much greater amount of data that can be used directly in making the numerous decisions required. These data permit a more accurate evaluation of the effects or costs of each of the different alternatives. Decisions can be made with a greater confidence that they represent the "one best way."

3.4 ONE PLANT OR SEVERAL?

In the discussion of the selection of both the region and specific plant site (Arts. 3-3.2), many factors were enumerated that must be considered in the selection. It was assumed that only one plant was to be located. Many growing industrial concerns are faced with the problem of deciding between a number of small plants and one large one. Where raw materials are more or less universally available, where no special skills are required, and where the market is represented by the general population, several plants, instead of one, usually represent the most economical solution. Each plant, however, must be designed for and operated at or near the optimum output. The cost of duplicating facilities which may not be used to capacity is one of the limitations that must be considered in the solution.

Soap, paper, gray cast iron, automobiles (assembly), synthetic fibres, millwork, furniture, plastics, fertilizer, and clothing are some products that have been decentralized with some success by individual companies.

4. FACTORY BUILDINGS

By far the greater amount of factory planning is in connection with the re-layout of existing buildings, but each year a large number of new buildings is added to the total industrial structure of the country. Each re-layout problem presents a challenge to the planning engineers to devise an efficient production arrangement within certain limitations, but the design of new buildings is an equally important challenge. Each new building is designed to house a particular production process, but it in turn becomes an "existing" building henceforth, and the care and thought that go into its design determine the relative ease of its re-layout when that time comes.

4.1 MODERN CONCEPTS OF BUILDING DESIGN

Probably more factory buildings were designed and constructed during the decade of 1941 through 1950 than in any other decade in history. The tremendous construction programs for both war production and civilian products provided many opportunities for architects and engineers to try new ideas and to accumulate results. A great amount of knowledge was gained about how to design factory buildings. It is impossible to review even a small portion of these trials and results in this volume, but a few generalities can be drawn from the experience to assist factory planners. A knowledge of these general principles will enable the factory-planning group to be of more specific assistance to the architects and struc-

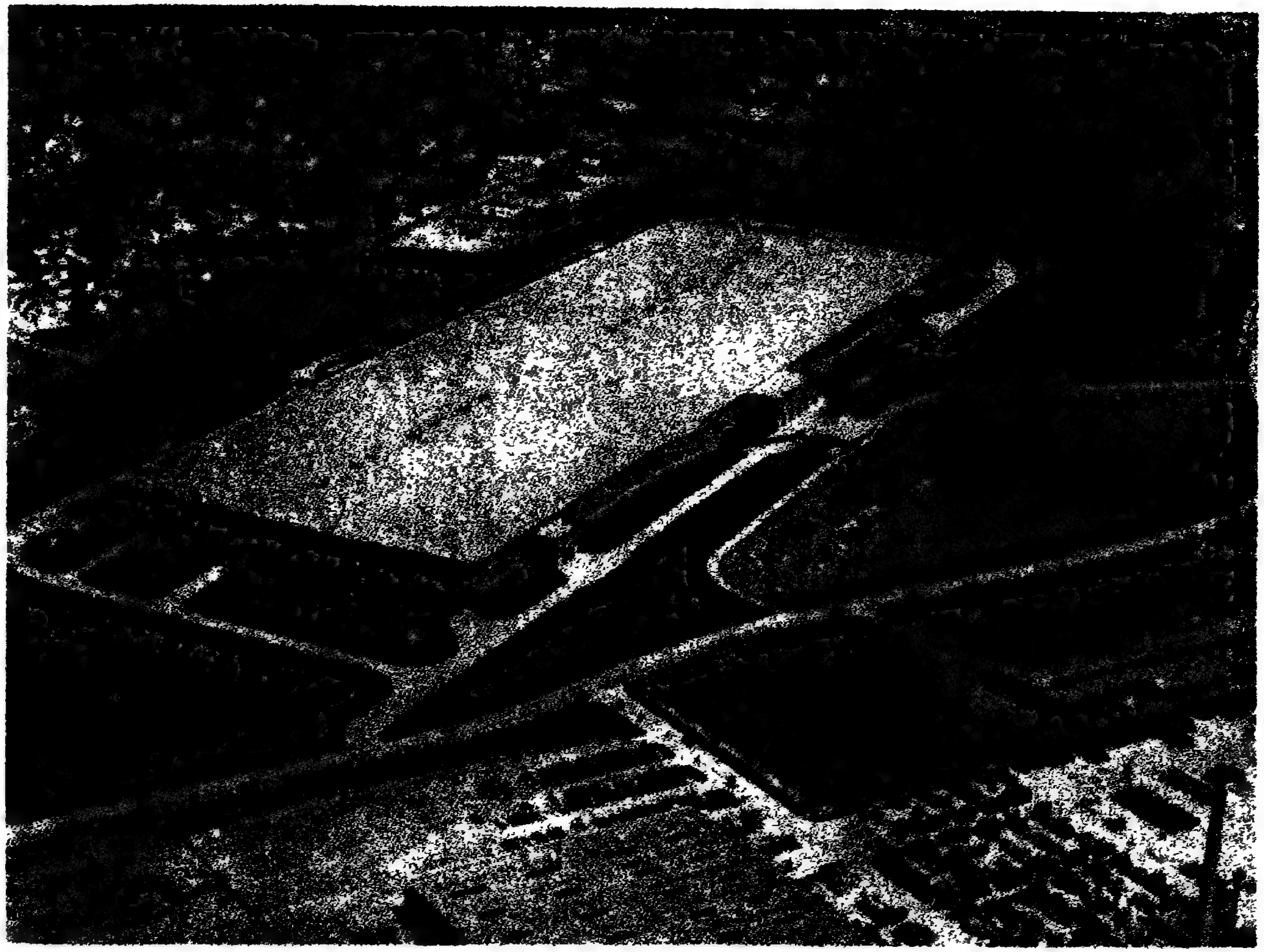
tural engineers when faced with the problem of designing a new building. The following paragraphs briefly report these principles.

One of the most significant developments came through the realization that the building's principal function is to provide protection for machines, equipment, personnel, materials, products, or company secrets. Thus, if the equipment need not be protected, it need not be housed. Refinery and chemical plant equipment has long been erected without housing; a building is provided only for the protection of operating personnel, records, instruments, and the like. If the climate is mild the year round, and if the equipment or products cannot be affected by rain or sun, then proper fences and the usual plant-protection police force may provide all the protection that is needed for the production process. The building may be needed only for offices, packaging, inspection, and similar functions. One plant in Texas has been constructed without exterior walls. Not only did the plan reduce construction costs (and capital tied up in fixed assets), but the relatively steady winds help to prevent the accumulation of explosive dust in the building (see Art. 3.3).

It has been shown that in most regions, where sufficient land is available at reasonable prices, a one-floor plant is more economical than a multi-story plant. Naturally, certain types of processes require a multi-story arrangement, but, where there is a choice, the old idea that gravity materials handling would justify additional floors has been largely disproved. It is true that a sphere incloses the maximum volume per square foot of exterior surface, but it is not true that the cost of a square foot of wall, floor, or roof is the same in a cubical building as in a one-story building providing the same floor space. The relative ease of constructing single-story plants, the rapidity of construction, the unlimited floor load capacities, the elimination of stairways and elevators, the greater flexibility of layout (vertically or horizontally), and the ability to expand or contract operations are some of the advantages of the single-floor plant that tend to make it more economical.

The construction for short-term war production taught that industrial plants designed for one product can be economically converted to the production of very dissimilar products provided the original plant was planned for flexibility. Aircraft plants have been converted to automobile and engine plants. Small arms ammunition plants have been converted to electronic products, chemical operations, plastic fabrication, and many diverse types of production. These conversions were usually made through the complete removal of existing machines and equipment and the addition of new equipment, and the re-layout has not always been ideal because of limitations imposed by the original construction. On the other hand, it has been learned that no plant (except some continuous-type factories) can be expected to remain as planned and originally arranged for long periods of time. Changes in products, design, demand, and the like, are inevitable, and efficient production will demand that rearrangements be made. Thus, a basic concept has been developed that plants for interruptible types of industry should be planned for great flexibility and ease of conversion or re-layout. (See Art. 2.5 for means of increasing flexibility.)

Techniques and construction practices are constantly changing and new materials of construction are constantly being employed. Speed of construction is important for several reasons (money tied up during construction period, immediate need for floor space, necessity to beat or meet competition, and so on), and where certain materials increase the speed of construction without increasing costs, there is a big incentive to use these materials. When costs of labor, freight, and lost time are considered, many of these materials are actually less expensive than conventional methods. Unfortunately, many of these newer materials and construction methods are not permitted under the building codes in some cities.



From Ireson, *Factory Planning and Plant Layout*, p. 311.
Courtesy The Lincoln Electric Company.

FIG. 8.2 VIEW OF THE LINCOLN ELECTRIC COMPANY'S NEW PLANT AT EUCLID, OHIO.

Some of these methods and materials are:

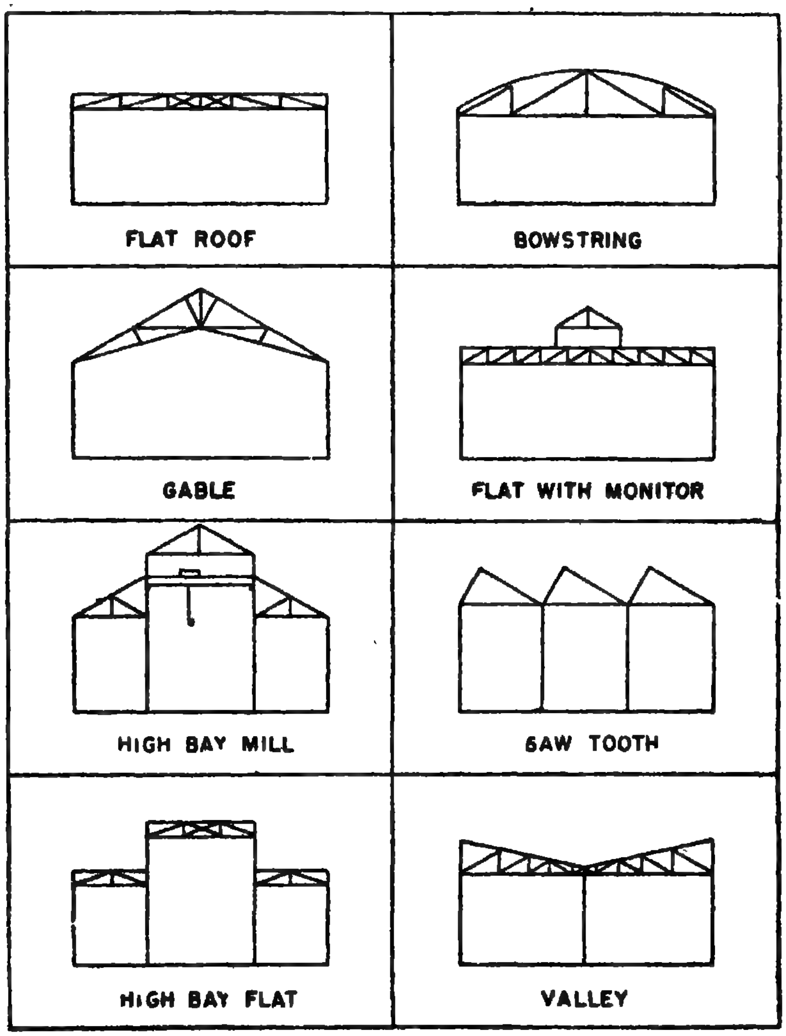
1. Use of precast walls, floors, and roofs. (Cast horizontally at one point and erected or "tilted up" at another.)
2. Use of pre-stressed concrete.
3. Use of light-weight aggregate.
4. Prefabricated buildings or sections of buildings.
5. Aluminum for structural members, wall covering, prefabricated panels, etc.
6. Insulated wall panels, with insulating core covered by metal or concrete.
7. Nonmetallic insulating boards or tile for built-up roofs.
8. Special treatments for concrete or ›d floors to preserve and reduce wear.

Names and addresses of companies supplying such materials can be found in various trade journals.

Building plans once corresponded to the shapes of such letters as I, L, H, E, and C, but most of the recent, one-floor plants have been simple rectangles or squares. Use of natural light and natural ventilation was the principal reason for the odd shapes, but the advent of low-cost power, efficient light sources and fixtures, and forced ventilation has largely overcome any advantages the older plans may have had. Greater floor space inclosed per foot of wall, greater flexibility in layout, and greater ease of materials handling are some of the other advantages of the large, simple plans.

Figure 8.2 shows the standard types of

FIG. 8.3 MOST INDUSTRIAL PLANT BUILDINGS ARE MADE UP OF COMBINATIONS OF THESE STANDARD TYPES.



From Ireson, *Factory Planning and Plant Layout*, p. 247.

factory buildings in common use. Although certain of these types have been popular for different industries, it is common to find two or more of these sections used in a single large building, depending upon the processes to be housed in the different divisions. It is necessary to consider the process, equipment, materials-handling systems, product, climate, and construction and maintenance costs in order to arrive at the best type for a given application.

4.2 BUILDINGS FOR CONTINUOUS INDUSTRIES

A second major concept of building design is that the production facilities should be completely planned, the ideal layout arranged, auxiliary facilities arranged relative to production facilities, and the building then designed around the complete plan. This procedure results in a very specialized building that usually will not be inherently flexible. This type of building design is usually employed only where there is an expectation that the original plan will remain unchanged for a long time. This concept is most often used by the continuous industries or to house certain highly specialized processes in what would otherwise be an interruptible industry.

Continuous industries plan for almost perfectly balanced production facilities, so that every division or department of the plant will have about the same capacity. The nature of the continuous industries is such that it is normally difficult to make changes after the plant is put into operation. The management goes to great lengths to assure that the equipment chosen, the layout, and the design of production facilities are the best currently available, so that the plant can enjoy a long period of operation without the danger that obsolescence will reduce the profit potential in a few years. The associated expenses of making alterations, adding new equipment, and changing processes make it difficult for a new piece of equipment to justify its installation on economic grounds. Thus a continuous industry expects its business to go on for many years, which really means that its building is unlikely ever to be used for any other purpose.

A long-established and financially sound company whose product is highly stabilized from the design viewpoint may choose this concept in order to obtain maximum efficiency and minimum costs. Thus, a large automobile manufacturer may build a highly specialized engine plant because there is little likelihood of radical changes in the design of auto engines for a long time. Minor changes can be easily accommodated in the specialized plant, and annual savings in operating expenses resulting therefrom may be sufficient to pay for the plant and earn a good return in a relatively short time.

4.3 EFFECTS OF EXISTING BUILDINGS ON LAYOUT

Whenever the production facilities are to be arranged within an existing building, some of the freedom of arrangement is lost. Each building feature becomes a fixed factor, or else the feature must be changed. Some of the variables in the general factory-planning problem become constants and the systematic approach to the problem is altered accordingly.

The building design should be the last step in the procedure of factory planning when a new building is contemplated. This is true because it is only after other factors have been analyzed that the total floor space needed can be estimated and the conditions determined that will establish the features to be incorporated in the building. When an existing building must be used for the production facilities, the approach is altered so that the effects of the building on each different alternative can be considered as each separate decision is made. The effect is usually to eliminate certain alternatives and to impose limitations on others, so that the decision may be greatly simplified. However, it may necessarily be lim-

ited to the selection of the best of several undesirable alternative arrangements.

When an existing building is to be used, the planning group should obtain as soon as possible complete information on the building and building conditions. This information should include:

1. Up-to-date blueprints of each floor, showing columns, walls (fire, load-bearing, temporary), windows, doors, stairs, elevators, and other physical features.

2. Accurate layout drawings of factory service piping and wiring, including sizes, capacity, and condition.

3. Layout drawings, showing the location of existing equipment and machines, whether this equipment will be used in new layout or not. Note size, vertical height, and sub-floor depth of each machine.

4. Plot plans of surrounding area, specifically showing any other buildings that may be used in connection with the one in question, driveways, rail sidings, contours of land, and elevation of this building relative to each of these items.

5. Blueprints showing the elevation views of each different section of the building, ceiling or truss clearances, floor levels, ducts, piping, wiring.

6. An engineering inspection report, giving:

a. Estimated safe floor loads.

b. Estimated costs of rehabilitation needed.

c. Estimated costs of proposed or possible changes.

d. Estimated costs of strengthening or reinforcing to give some minimum safe floor load.

Each of the preceding items limits the re-layout of the facilities and the alterations that might make the building more usable for the intended purposes. The planning engineers study these limitations and then establish the possible alternative arrangements, considering such factors as the space required for each department compared to that available, weights of machines and materials compared to safe floor loads, sequence of operations, materials-handling facilities and costs, and special conditions or hazards associated with the several departments. Each of the possible alternative arrangements will be analyzed and compared by engineering economy methods.

5. THE LAYOUT OF PRODUCTION EQUIPMENT

5.1 PROCEDURE FOR PLANT LAYOUT

Plant layout is just one limited phase of factory planning (see Art. 1). The layout of a factory generally consists of a number of separate problems of arrangement of facilities, and each problem is small enough to be manageable. This statement is not obviously true, especially if the plant involved happens to be a large and complex one. However, the procedures described in the following articles are designed to assist in the breakdown of a complex problem into a number of smaller problems that can be handled with relative ease. The more complex the product becomes, the more important it is to follow a systematic method to simplify the problem.

The procedure should first guide the planner's actions so that the probability of his arriving at an optimum arrangement is maximized, and, second, it should provide him with a basis for judging the relative merits of any one proposed layout versus others. In other words, the planner needs a road map to guide him to the best solution and a sign to tell him when he has arrived at the proper arrangement. At present, there are a number of general principles that help the planner find the best way, but little has been accomplished yet in developing a usable, foolproof mathematical model. The matter of criteria for judging the relative value of different proposals is being investigated in many places,* but at this time the best measure is the

* John R. Hoffman, *An Evaluation of Quantitative Techniques in Plant Layout,* a paper presented before A.S.M.E., Los Angeles, June 1953; Logistics Research Project, University of California, Los Angeles. Sponsored by the Office of Naval Research; R. B. Petit, *A Further Extension and Evaluation of Criteria of Physical Plant Utilization,* M.S. Thesis, Purdue University, June 1951.

prospective unit cost resulting from each proposed layout.

The following articles describe the procedure employed in the re-layout of existing facilities for the manufacture of a given product. It is assumed that the product, or a similar product, has been manufactured previously, and that the facilities must be arranged in an existing building. This is the most common layout problem, but special procedures to use when the product is entirely new, when new machines or equipment are to be used, and/or when a new building is to be used are given later. These procedures follow, in general, the pattern established in Art. 2.1.

5.1.1 Collect all factual data:

1. Obtain or prepare an up-to-date print or drawing of the existing layout of the facilities to be rearranged.

2. Secure an accurate description (print and engineers' report) of the building and building features (see Art. 4.3).

3. Collect complete information on the product design and present manufacturing methods. This should include:

a. List of parts and drawings for each part (see Fig. 8.4).

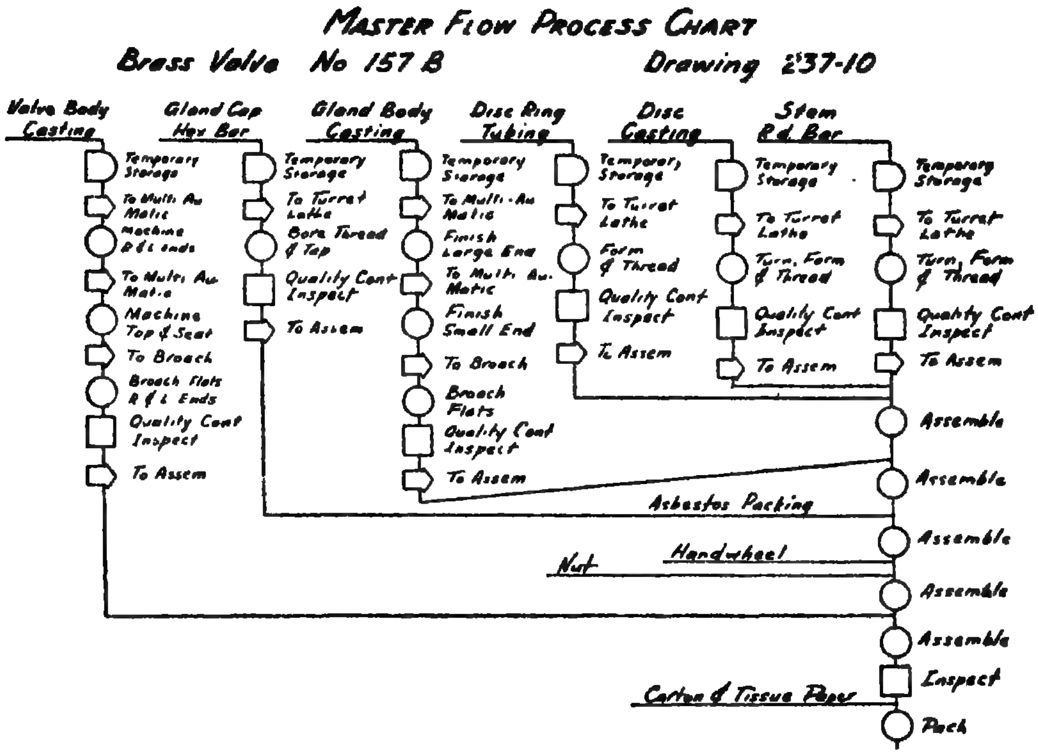
FIG. 8.4 PARTS LIST FOR A BRASS VALVE.

PARTS LIST

PRODUCT Brass Valve CATALOG NO 157-B
SIZES ½", ¾", 1" & 1¼" DRAWING NO 237-10
MANUFACTURE TO STOCK ☑ SPECIFICATIONS All Brass
ORDER ☐ Std. Pressure, see Drawings
PACKED 1 per Carton
12 Cartons per case

PART NO.	PART NAME	DRAW NO	MATERIAL	QUAN PER UNIT	SOURCE
157-B1	Valve Body	237-11	Brass Casting	1	Make
" -B2	Gland Body	"	" "	1	"
" -B3	Stem	237-12	Brass Rod, Rd	1	"
" -B4	Gland Cap	237-11	Brass Hex Rod	1	"
" -B5	Handwheel	237-12	" "	1	Purchase
" -B6	Nut	" "	Brass	1	"
" -B7	Disc Ring	237-13	Brass Tubing	1	Make
" -B8	Disc	" "	Brass Casting	1	"
" -B9	Packing	237-11	Asbestos-Graphite	1	Purchase
" -B10	Tissue Paper	—	18" × 24"	1	"
" -B11	Carton	237-14	Cardboard	1	"
" -B12	Case	237-14	Wood	1/12	"

From Ireson, *Factory Planning and Plant Layout*, p. 18.



From Ireson, *Factory Planning and Plant Layout*, p. 19.

FIG. 8.5 MASTER FLOW PROCESS CHART FOR A BRASS VALVE.

b. A flow process chart for each part by present method of manufacture.

c. A master flow process chart for each part and the assembly of the final product (see Fig. 8.5).

d. Obtain standard instruction sheet for each operation, showing tooling, machine, jigs, fixtures, etc., and the standard production time for the operation.

4. From the sales department, obtain the results of the market survey and sales forecast for the product. Tabulate the prospective quantities by periods or years for the prospective life of the new layout. If the product is subject to seasonal fluctuation, prepare a chart showing the probable fluctuations by months.

5. Determine the budgetary limitations within which the new layout must be made, such as:

a. Amount of money that is available for the project.

b. Criteria by which investment of funds in re-layout, new equipment, tools, or materials-handling facilities must be justified (see Section 3, Art. 15).

c. Managerial policies that will affect the freedom of choice in making the re-layout. May production be stopped or must it be maintained during the change? May re-layout extend beyond immediate problem if that will simplify the re-layout problem? Is management wholeheartedly behind the factory-planning group, or will each proposal have to be "sold" against active resistance?

6. Make a survey of existing materials-handling facilities that affect this problem. This survey should be designed to determine the nature and effectiveness of the present facilities (see Art. 7.4). It should include:

a. Inventory of equipment, with an evaluation of its current condition and prospective life.

b. Current materials-handling costs (not only the actual operating costs, but also those resulting from interruptions in production caused by the system, damage to materials and parts, and cost of supervision and coordination).

c. Adaptability of existing facilities to

work with other handling equipment and layouts.

7. Secure a report on the labor supply available for present and future operations of this division. The report should provide information on the scarcity of unskilled, semi-skilled and skilled labor, male or female, and going rates.

These factual data are generally available from the methods and standards, production planning and control, personnel, and sales or marketing departments, and the factory management. Every effort should be made to obtain as complete and accurate information as possible, because lack of information or errors in data can cause the planning group to spend a great amount of time and effort on proposals or solutions that are impracticable or completely impossible.

5.1.2 Separate fixed and variable factors and attach quantities or numerical values wherever possible.

1. Analyze each item of information collected in the first stage (Art. 5.1.1) and determine whether or not it can or will be changed, or whether it is a factor that will vary with business activity, economic conditions, promotional programs, and the like. For example, if present machines must be used (possibly because no capital is available even if new machines might be more economical), the freedom to devise new and better operations and operation sequences is limited by the capabilities of the existing machines. On the other hand, the cost of different materials or different grades of labor may be variables that depend upon a number of factors, and it is necessary for the planning group to consider the probable variations in each in order to arrive at the combination of materials, operations, and kind of labor that will give the optimum plan.

2. Prepare a list of fixed factors. These fixed factors are conditions that must be satisfied if they are not to impose certain physical limitations on the proposed plans.

3. Prepare a list of variable factors and establish probable limits of variation for each. This step emphasizes the fact that many of the data are estimates of future activity and should not be treated as absolute quantities. The maximum capacity of output may be the basis for computing the number of machines and for balancing producing units, but the effects of operating at an output below this maximum must be considered in making the final layout and production plan.

5.1.3 Investigate all possible improvements that can be incorporated in the new plan. This is a study of manufacturing methods made in cooperation with other departments. It should cover such items as:

1. Machines and equipment: Are there other types of machines that can be used more economically for the operations?

2. Tools, jigs, fixtures: Will better accessories enable the operations to be performed more rapidly, more accurately, with less skilled labor, or to be combined with others? (See Section 10.)

3. Standard practices: Can the work place be improved, better procedures be devised, operations or movements be eliminated, simplified, or combined, and operation sequences be changed? (See Section 5.)

4. Materials handling: Can better use be made of existing materials-handling equipment, better equipment be employed, movements be eliminated or shortened, transport and transfer be combined, or semi-automatic or automatic equipment be substituted? (See Art. 7.)

5. Materials: Can other materials be substituted for present materials in order to reduce material, labor, or processing costs while maintaining or improving the product quality?

6. Personnel: How can personnel facilities be improved to reduce fatigue, improve morale, or improve efficiency? (See Section 12, Arts. 4 and 5.)

This phase of the investigation is most important, for it provides the planning group with definite ideas for consideration in arranging the new layout. The planning engineer should discuss each phase of the manufacture with the individual workmen, foremen, methods engi-

neers, designers, inspectors, and purchasers or buyers in order to uncover every possible difficulty that has been encountered in the past. At the same time, the engineer should seek suggestions from these persons and make careful notes of the suggestions and sources. He should also be so familiar with the several parts that he can anticipate difficulties and use direct questions to ascertain the facts regarding these ideas. It is a cardinal principle that the optimum alternative cannot be selected unless every possible alternative is recognized and investigated.

The planning engineer must also recognize that he is dependent upon the other departments in the plant for information and suggestions. Thus it pays him to cooperate fully with other departments in order to induce these departments to do as much of this investigation as possible. It is, however, his responsibility to talk with and stimulate the thinking of the members of the cooperating departments.

5.1.4 Determine the auxiliary departments or services that must be provided for this manufacturing setup. Certain auxiliary departments and services may be needed in the immediate vicinity of the manufacturing area, and provisions should be made for them in the initial planning of floor-space utilization. Services that do not require floor space or special treatment, or departments that do not require physical proximity to the manufacturing facilities, need not be considered at this stage. Some of the items that may be necessary are:

1. Tool room, tool maintenance or die shop.
2. Foremen's offices, clerical offices, etc. (see Art. 6).
3. Inspection rooms, gage storage, and maintenance (see Section 14, Art. 9.9).
4. Materials-handling facilities, such as conveyors, aisle widths to accommodate trucks or tractors, crane ways, etc. (see Arts. 5.5.4 and 7).
5. Personnel facilities (see Art. 5.5.6).
6. Storage facilities for raw materials, supplies, work-in-process, and finished parts (Art. 5.5.5).

5.1.5 Make basic decisions and establish feasible alternative methods of arranging the factory. The total number of different ways of arranging the production and service facilities is very large, approaching the permutation of the number of factors, machines, parts, and other contributing conditions. At this time it is not practicable to attempt to solve such a large set of conditions for the optimum by either intuition or mathematical models (see Section 15). In order to reduce the problem to a size that can be handled by the human mind, *it is necessary to eliminate whole sets of alternatives by analysis of past experience, records, and so forth in relation to the present problem.* Both inductive and deductive reasoning are employed to arrive at the conclusion that certain combinations are not worthy of future consideration, that certain factors or conditions naturally complement each other, and that the best possible solution must lie among a very limited number of combinations. This is a matter of analysis of facts and estimates, rather than the practice of an art. The reduction of the number of combinations makes it possible for the human mind to encompass the essentials and arrive at a reasonable solution. The following basic decisions help to accomplish this reduction and enable the planner to progress step by step toward the optimum solution:

1. What method of departmentalization will be used—product, process, or a combination for the several parts? (See Art. 5.3.)
2. How should the several departments be arranged within the building space, considering building characteristics, nature of processes, space requirements, etc.? (See Art. 5.4.)
3. What materials-handling facilities are most suitable and economical considering the nature of the parts, materials and products, type of movement required, processing methods, distances involved, etc.? (See Art. 7.)
4. What method of determining the arrangement of machines and equipment within the departments will be most sat-

isfactory from the viewpoint of time required to reach a solution, cost of making the layout, cost of the tools employed, and value of the tools in the future? (Sketching or drafting, two-dimensional templates, or three-dimensional models.) (See Art. 5.5.)

These basic decisions must be treated as tentative, for as the details are worked out it may become necessary to change the decisions partially or totally. Such a development is inconvenient, but should not be looked upon as a failure of the procedure. The decisions were made on the basis of their probability of being best, but they can be proved only by actual computation of their results.

5.1.6 Prepare and test the several alternative arrangements, choose the best, and prepare the report to management.

1. Block out the estimated department boundaries on the building floor plan.

2. Using one of the layout methods, arrange the machines within the department boundaries, making adjustments as necessary.

3. Analyze each arrangement to determine comparative costs of production, materials handling, supervision.

4. Have best plan reviewed by interested persons (workmen, foremen, and representatives of methods, production-control, personnel, materials-handling, and design departments). Obtain criticisms and revise plan if necessary.

5. Prepare schedule for the installation.

6. Prepare final plan for management's approval.

5.1.7 Prepare complete instructions for the re-layout and supervise the installation.

5.1.8 Collect data on the operation, and locate and correct any faults that may have been incorporated. It is usual, especially in highly mechanized production, to find a number of "bugs" in a new layout, and the planning group is not relieved of responsibility until the plan is functioning satisfactorily.

5.2 The layout of new facilities. Layout deals with three basic factors: product, building, and equipment. Each of these factors may be "new" or "old" (existing), which means that there are eight combinations:

	Product	*Building*	*Equipment*
1	Old	Old	Old
2	New	Old	Old
3	Old	Old	New
4	New	Old	New
5	Old	New	Old
6	New	New	Old
7	Old	New	New
8	New	New	New

The procedures for handling combinations number 1 and 2 were given in Art. 5.1. Variations in the procedure to accommodate the other combinations follow.

5.2.1 New equipment. Combinations 3, 4, 7, and 8 involve new machines and manufacturing equipment. Some existing equipment may be available, but a substantial amount of new equipment is to be obtained. This fact introduces new variables, since there are usually several different kinds, models, or types of machines that will perform a certain operation. This choice of new equipment can be made only after complete information about each type has been accumulated, and after the equivalent cost of using that machine has been computed.

Simultaneously, the fact that new equipment is to be obtained removes some of the limitations on tooling, methods improvement, sequence of operations, and capacity of output. The existing flow process charts become guides or check lists, rather than fixed routes. There will be more uncertainty about the output and operation problems of the new equipment than about existing equipment. The procedure will be altered to include investigations of the proposed equipment by going to other companies that are using similar equipment. The fact that different types of equipment will perform different combinations of operations requires that all the alternative combinations of providing the required operations be studied. Over-all economy is the objective and all the equipment for the production of a single part or series of parts must be considered as a unit.

5.2.2 New buildings. Combinations 5, 6, 7, and 8 involve new buildings. For this purpose, it is assumed that a new building is one that is to be built and does not now exist. This condition removes the limitations of an existing building and provides greater freedom for the layout. Its principal effect on the layout procedure is that the building need not be considered until after the equipment has been selected, the departmental arrangements determined, the materials-handling system selected, and the equipment layout made. In other words, whether the building is to be a general-purpose or a special-purpose building, its design need not be frozen until after the important building features have been determined from a study of the production problems. Thus, it can be assumed during the planning stage that a suitable building can be designed to accommodate the optimum layout.

5.2.3 New product. Combinations 2, 4, 6, and 8 involve new products rather than existing products. The degree of "newness" will determine the necessary changes in the procedure described in Art. 5.1. If the product is just a redesigned product with essentially the same parts and without drastic changes in the materials, shapes, or sizes, there will be very little change in the procedure. On the other hand, if it is an entirely new product, not similar to anything previously manufactured, there is little prior information available. The planning group, in conjunction with the methods, production control, and design departments, will have to prepare new operation sheets, flow process charts, tooling designs, methods, time standards, and so forth. The more foreign this product is to previously manufactured products, the greater is the probability of errors in the estimates and of "bugs" or faults in the final arrangements.

5.3 METHODS OF DEPARTMENTALIZATION

5.3.1 Departmentalization principle. The general principle of departmentalization of production facilities states: *"That method of departmentalization is best which provides for the production of the required quantity and quality of a product at the desired time and at the lowest over-all cost of production in the long run."* * There are three recognized methods of organizing the production facilities of a factory by departments:

Product or line.

Process or functional.

Combination of the two.

Each of these methods of departmentalization has certain advantages and disadvantages. The decision on which method to use in a given situation depends upon the conditions that must be met. Figure 8.6 summarizes the advantages of product and process layout and lists the usual conditions that indicate the use of each.

No one method should be adopted without examining the possibility of using the other methods for some departments or products. Two or three methods are commonly used within a single building of a multi-building plant. Many companies employ the combination method for the layout of fabrication and processing, line method for assembly and for some particular parts, and process layout for painting or finishing and packaging for shipment. The object is, of course, to minimize the cost of production in each phase of production by adopting the optimum method.

5.3.2 Line or product layout. In the line layout, all the equipment required for one part or product is grouped together in one department in the sequence of the operations performed, so that the part is completed there and does not have to be moved from department to department for processing. The line is "balanced," in that the output capacity of each different type of equipment (or process) is the same or as nearly so as practicable.

Ordinarily, only one product is processed by one line department. How-

* W. Grant Ireson, *Factory Planning and Plant Layout* (New York: Prentice-Hall, Inc., 1952), p. 48.

PRODUCT VS. PROCESS LAYOUT

Relative Advantages of Product and Process Layout

PRODUCT LAYOUT	PROCESS LAYOUT
1 Lower total materials handling cost	1 Less duplication of equipment, hence lower total investment in equipment
2 Lower total production time	2 Greater flexibility of production
3 Less work-in-process	3 Better and more efficient supervision possible through specialization
4 Greater incentive for groups of workers to raise level of performance (and greater possibility for group incentive pay plans with broader coverage)	4 Greater incentive for individual workers to raise level of performance (and greater possibility for individual incentive pay plans)
5 Less floor area required per unit of production	5 Better control of complicated or precision processes, especially where much inspection is required
6 Greater simplicity of production control — fewer controls and records needed, lower accounting cost	6 Easier to handle breakdowns of equipment by transferring work to another machine or station

When to Use Product and Process Layouts

PRODUCT LAYOUT	PROCESS LAYOUT
1 One or few standard products	1 Many types or styles of products, or emphasis on special orders
2 Large volume of production of each item over a considerable period of time	2 Relatively low volume of production on individual items (though total production may be high)
3 Possibility of time and motion studies to determine rate of work	3 Adequate time and motion studies difficult or impossible to make
4 Possibility of good labor and equipment balance (each machine or work station producing equivalent number of units per hour)	4 Difficult to achieve good labor and equipment balance
5 Minimum of inspection required during sequence of operations	5 Many inspections required during a sequence of operations
6 Minimum of very heavy equipment or equipment requiring special facilities (isolation from general production areas, etc.)	6 High proportion of very heavy equipment or equipment requiring special treatment
7 Materials and products permit bulk or continuous handling by mechanical means	7 Materials or products too large or too heavy to permit bulk or continuous handling by mechanical means (in extreme cases, process may have to be brought to work, instead of vice versa)
8 Little or no occasion to use same machine or work station for more than one operation (minimum number of setups required)	8 Frequent necessity to use same machine or work station for two or more different operations

From Ireson, *Factory Planning and Plant Layout*, p. 54. Adapted from "Adopt the Best in Plant Layout," by Carroll W. Boyce, a special report in *Factory Management and Maintenance*, September, 1949, and reproduced by permission of the author.

FIG. 8.6 PRODUCT VERSUS PROCESS LAYOUT.

ever, it is frequently possible to change the tooling on the machines and thereby use the same sequence of machines for the production of some similar part. Although it is quite common to use the same production line for manufacturing the same part in a series of sizes, entirely different parts, which happen to require the same or almost the same sequence of machine tools, may be produced on the line. This situation may make it possible to devise an efficient line layout for two or more products neither of which individually would justify the line.

A line layout is not usually a *straight* line. In fact, a straight line usually indicates inefficient use of floor space and greater intra-departmental handling costs. The ideal line is one in which the product of one machine automatically feeds into the next, and so on. Transfer machines, carrousel arrangements, automatic cleaning, dipping, spraying, and drying of paint by conveyorized movement of parts, and many other automatized production lines have been devised. If each machine must be attended by workmen, it is desirable to arrange the machines in such a way that each operator can conveniently pick up the part from the place where it was deposited by the previous operator. Conveyor belts, chutes, slides, and trays on short lengths of gravity roller conveyor are used when the size and shape of the machines make the direct arrangement inconvenient. The actual path of the part through the line department may be a straight line (in order to employ a flat belt conveyor), but it is more likely to be similar to the shapes of such letters as S, U, L, M, N, O, Y, or C, depending upon the number of machines involved, the shape and size of the floor space available, the size and weight of the product, and the number and duration of the operations performed on the part.

In addition to those conditions listed in Fig. 8.6, the following conditions tend to dictate the use of line-type layout:

1. The discovery that a slight reduction in the selling price of a product will produce a large increase in the demand.

2. The discovery that two or more products have operations that are performed on the same types of machine and in the same sequence.

3. Difficulty of maintaining production control if produced by a process layout.

4. Difficulty in finding highly skilled employees for the existing functional layout.

5. Complaints from foremen over crowded conditions, lack of storage, materials-handling delays, lack of capacity, or overtime work.

The line layout usually has certain unique characteristics:

1. Conveyorized, automatic, or semiautomatic materials handling, with most of the in-process inventory in temporary storage on the materials-handling system.

2. Small in-process inventory and short production cycle.

3. Mechanical pacing, partially or completely.

4. A labor force that is mostly unskilled or semiskilled.

5. The operation of two or more machines by one operator.

6. The utilization of more specialized tools, jigs, fixtures, and machines.

7. Little or no flexibility in the volume of output (in a given time period) or in product design. Little or no opportunity to use the machines for other products during slack period.

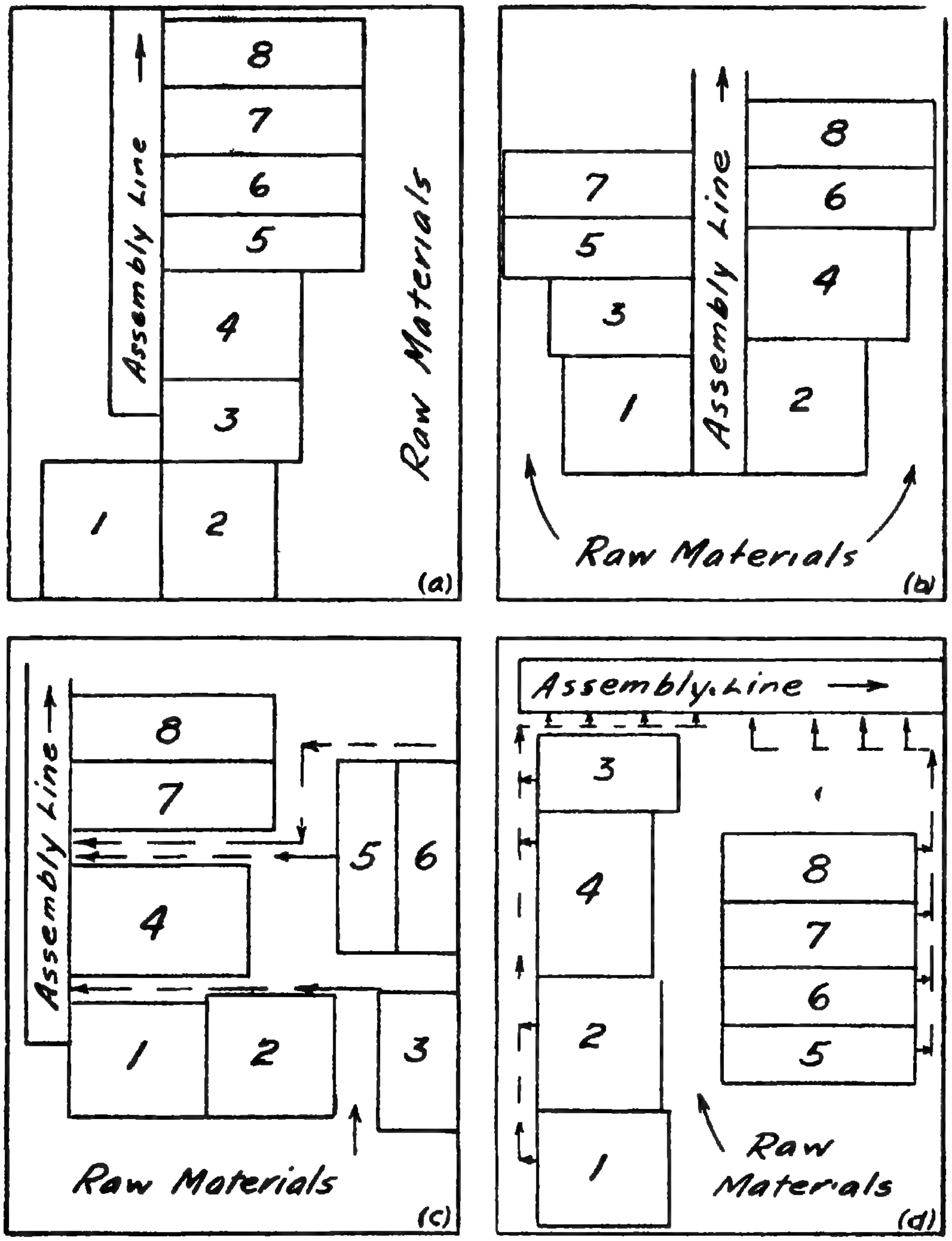
8. The possibility that one breakdown will interrupt a whole line.

9. A high investment in specialized equipment that may have little or no resale value.

10. Less necessity for written orders and records to obtain and maintain the desired production control. No detail scheduling for individual machines in the line.

11. A need for supervisors to be familiar with widely diversified operations.

Assembly lines are customarily fed by a number of product departments that fabricate the individual parts. An at-



From Ireson, *Factory Planning and Plant Layout*, p. 58.

FIG. 8.7 FOUR POSSIBLE WAYS OF ARRANGING EIGHT PRODUCT LINES FEEDING AN ASSEMBLY LINE.

tempt is usually made to arrange the product departments along the assembly line and in the sequence of assembly so that the parts are fed directly to it. For many reasons, this is not always feasible, and parts may be fabricated at a considerable distance from the point of assembly. The importance of having the feeder line near the assembly line decreases as the size and weight of the part decrease, as the ease of handling increases, or as the cost of making special arrangements near the assembly point goes up. Figure 8.7 shows a number of ways of arranging product-line departments in conjunction with an assembly line.

5.3.3 Process or functional layout. In

the process or functional method of layout, the department is made up of machines, equipment, or processes that fall into one category, according to the functions performed. The product is fabricated by moving it from department to department according to the sequence of operations to be performed on it. The operations performed in each department are assigned to particular machines within the department according to the capacity required, availability of machines, precision required, and so forth. Functional layout is general-purpose layout, and provides for great flexibility in output, design of products, and methods of production. It minimizes the seriousness of a breakdown.

The functional layout is characterized by such conditions as:

1. The presence of a skilled labor force, capable of setting up the machine, reading blueprints, and determining the proper sequence, feeds, and speeds for efficient operation.
2. Highly specialized supervision in each department.
3. Many different production orders in process at the same time, resulting in a need for careful control and direction.
4. Large storage space in each department for work-in-process and large in-process inventories.
5. Extensive materials-handling operations; frequent movement of small quantities over medium and long distances.
6. Generalized materials-handling equipment, requiring a large amount of labor and supervision.
7. The need for large volumes of instructions, written and oral, to effect desired movements and operations at desired times.
8. Frequent changes in workers' jobs and frequent instruction.
9. No mechanical pacing of the work.
10. A possibility of making greater use of machines and requiring less capital investment.

5.3.4 The combination layout. The combination method of layout is feasible when a number of products require about the same sequence of functional operations but none enjoys sufficient volume to justify individual production lines. The principle of this method lies in the arrangement of functional departments across the building at right angles to the flow of product and in the required sequence of operations. Particular sections of each department are assigned the different lines of products, but the sections can be adjusted as volumes change to accommodate larger or smaller orders. Figure 8.8 shows a typical combination layout.

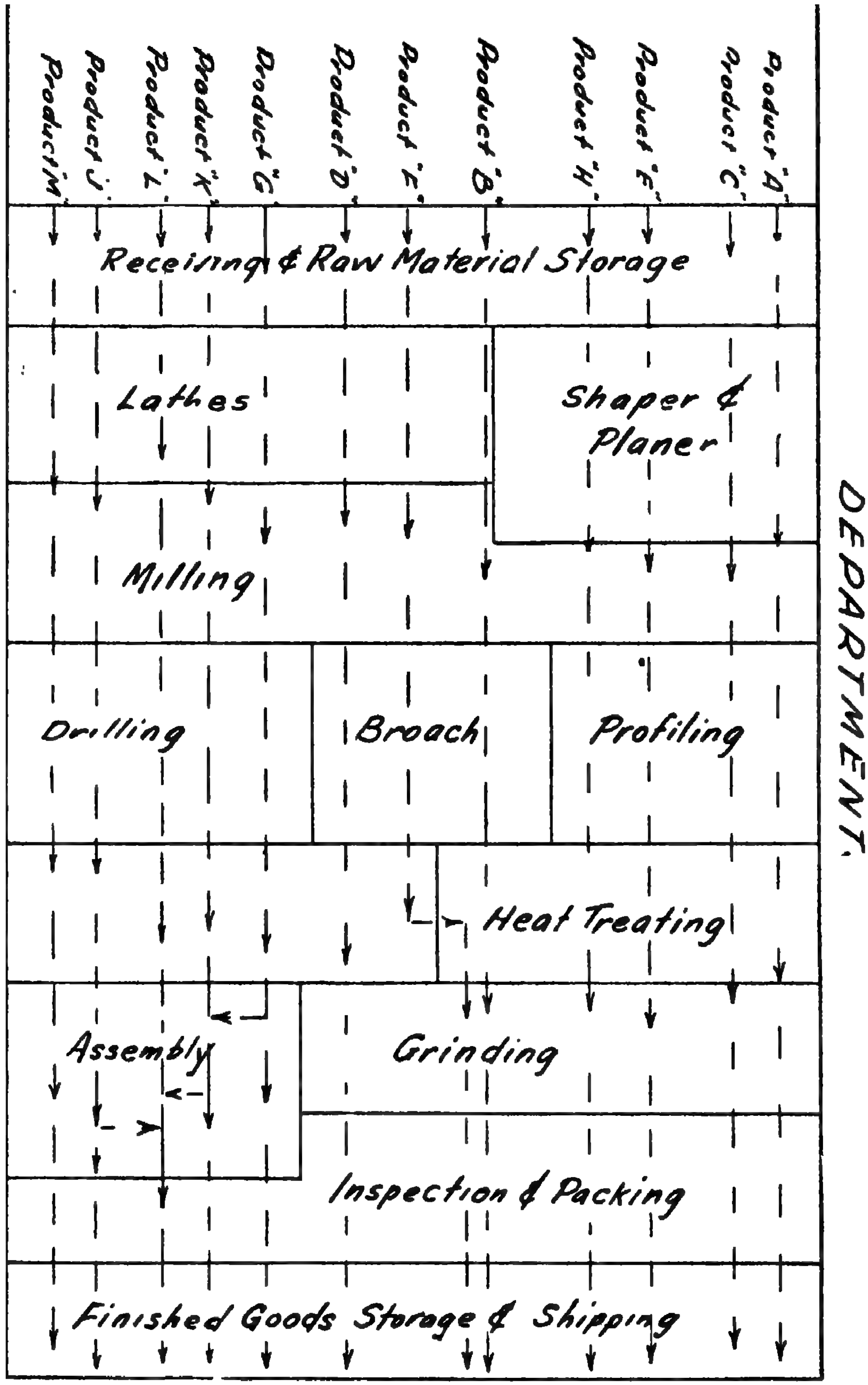
Another example can be taken from the manufacture of steel office furniture or other hollow steel products. The sequence of operations for each component part is generally the same:

1. Shear or blank stock for part.
2. Punch and notch blanks.
3. Bend or form blanks.
4. Deburr as required.
5. Spot-weld or gas-weld component parts into subassemblies (drawers, legs, pedestals, tops).
6. Finish (clean, dip, sand, spray, bake, etc.).
7. Assemble final product.
8. Install hardware (locks, drawer stops, hinges, etc.).
9. Pack and ship.

A company producing several different styles of desks, filing cabinets, chairs, cabinets, tables, and so forth, can make profitable use of such a layout.

5.3.5 Analysis of product and process layout. An example will serve to show the effects of layout method on the production cycle time and the in-process inventory. It also shows how the line layout is a natural development resulting from refinements of the process layout.

Assume that a certain part, weighing 75 pounds, has an annual volume of 400 pieces, produced in four lots of 100 pieces each. Three operations (others omitted for simplicity) are necessary, requiring 30 minutes, 20 minutes, and 45 minutes, respectively, on machines no. 1, 2, and 3. Two hours are allowed for the movement of a load of parts from one operation to the next. Figure 8.9 shows several ways of scheduling



From Ireson, *Factory Planning and Plant Layout*, p. 45.

FIG. 8.8 AN ILLUSTRATION OF THE COMBINATION METHOD OF DEPARTMENTALIZATION.

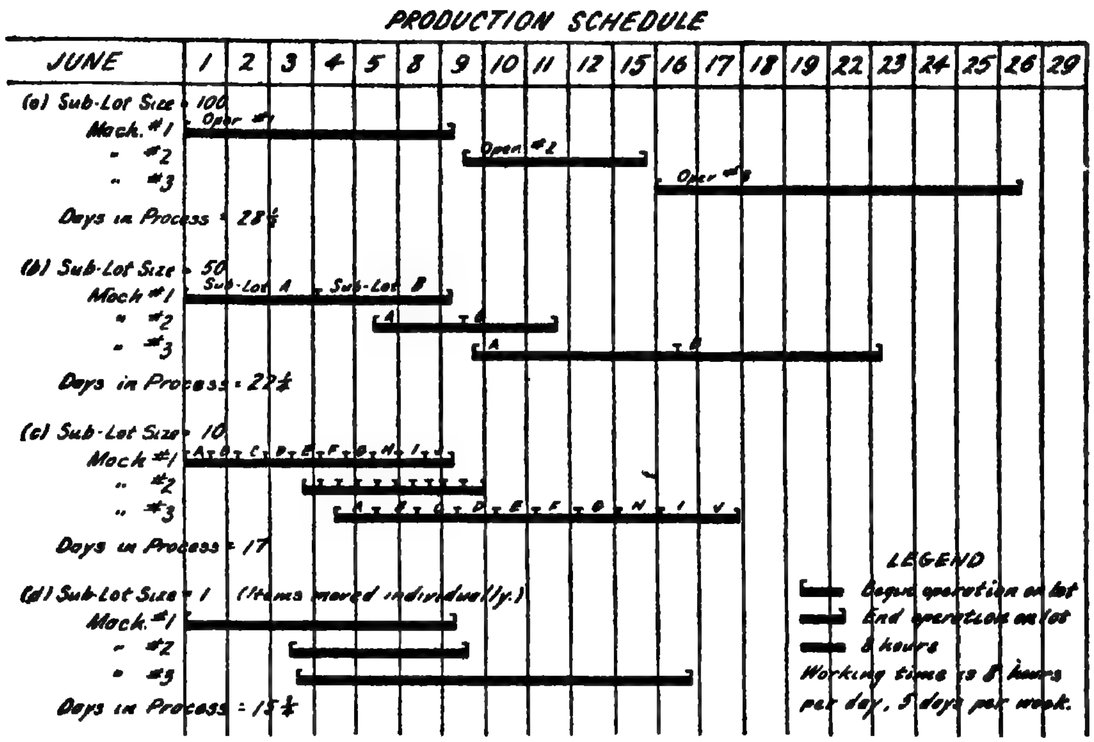


FIG. 8.9 EFFECTS OF SUB-LOT SIZE ON OVER-ALL PRODUCTION TIMES AND SCHEDULES.

this job, using sublots of different sizes as follows:

(a) 100
(b) 50
(c) 10
(d) 1

In each case, the production has been started on June 1, and 100 units have been completed as quickly as possible. Each sublot is scheduled to the next full hour except for (c) and (d). The schedule is also made in such a way that after a machine has been set up there will not be any idle time on it. Set-up times have not been included.

It is obvious that it is not practical to try to handle 100 units in one "unit load" (see Art. 7), since that means that schedule (a) would have to be used, and the entire 100 units are tied up in-process for 28½ days. None can be packaged or shipped prior to June 29. If the lot is broken into two sublots (two unit loads), the first sublot is ready for packaging and shipment on June 16. Furthermore, the longest cycle time, sublot B, is just 20 days. If 10 sublots of 10 units each are used, the first 10 can be packaged on June 5, a total cycle time of 5 days, and the longest cycle time will be for sublot J, about 8 days.

Little is gained by reducing the sublot to a single unit (the assumption that each piece will be moved independently), but (d) shows what would happen if the three machines were placed along a roller conveyor. Machine no. 1 would build up a bank ahead of machine no. 2 before machine no. 2 starts working. As soon as no. 2 starts it reduces the bank or float more rapidly than machine no. 1 replenishes it. The two-hour move time here becomes a safety factor, so that when machine no. 1 finishes its last piece, machine no. 2 has two hours of work, or 6 pieces, ahead of it. When machine no. 2 started, it built up a bank of two hours' production (6 pieces) before machine no. 3 started, and continued to build up the bank faster than machine no. 3 used it at the rate of 45/20. The largest bank occurred when machine no. 2 finished its last piece. At that time, there were 62 pieces in the bank ahead of machine no. 3.

As the sublot size is increased—(c), (b), and (a)—the maximum bank or float increases, necessitating greater and greater storage space between each pair of operations.

Such calculations as these provide a basis for deciding whether to employ a line or process layout for a particular product. They establish the data from which storage capacity, conveyor spacing, conveyor speeds, and production schedules can be computed. The ideal line is developed when the number of machines and operations is balanced perfectly, so that each one is taking the same amount of time, and so that the bank is the minimum size for safety from interruption.

5.3.6 Temporary production lines. Many companies have developed techniques for setting up product line layouts for short-run production. The basic principle behind this development is that it may be less costly to rearrange machines into a production line than to transport the materials from department to department of a functional layout. The necessary flexibility in layout is accomplished by:

1. Mounting light and medium-weight machines on platforms, skids, or casters so that they can be moved easily and quickly by a fork lift truck, an overhead crane, or a tractor. Machines must be stable without being fastened to the floor.

2. Locating heavy machines at such intervals that the necessary light machine can be arranged around them to form a production line under widely varying conditions.

3. Providing readily accessible services. The installation of a grid system of bus duct for power distribution and piping for compressed air, steam, water, and so forth, facilitates the rapid changeover between production runs.

Such a plan has disadvantages that should be carefully evaluated before embarking on the plan. It is highly probable that the company will have to have a larger number of machines than it can keep operating, but this may also be true for the company if it does custom work and employs the functional layout. This possibility requires that an extensive study be made of materials-handling costs, and that standard data be developed that will enable the production-planning department to decide whether or not to set up a special line each time an order is received. If orders of any size are to be accepted, it will be necessary to maintain a functional layout to handle the small orders in addition to providing space and machines for the temporary line layouts. Unless all machines can be interchanged between the line and functional departments, a less efficient machine may have to be used on certain jobs because the better machine may be assigned to the other departments. This plan places great emphasis on scheduling, and poor control can render the plan almost useless (see Section 6).

5.3.7 The equipment list. In order to arrive at the correct decision regarding the departmentalization method, it is necessary to tabulate the kinds of machines and equipment to be used and the amount of time each product will occupy each type. The flow process sheet is the logical place to accumulate the information on machine requirements for individual parts. An extra column can be added to show the product of the standard time per piece and the number of pieces to be run per week, month, or year. This is the machine-hour capacity required for that part. A second column can be added for the equivalent number of machines, which is the machine-hour capacity required divided by the standard number of working hours for the base period (week, month, or year). If flow process charts do not exist, and are not needed for other purposes, a form such as that shown in Fig. 8.10 can be used to show both the sequence of operations, the machines, and the machine capacity required. Such a form immediately shows the number of machines that would be required for a product line (rounding the values to the next larger whole integer) and points out the difficulties to be encountered in balancing the line. If the product is to

MACHINE CAPACITY WORK SHEET

PART NAME *Valve Body* SIZE *1/2"*

PART NUMBER *157-B1* QUANTITY PER *Mo* . *3000*

SIZE AND WEIGHT OF PART *1" x 1" x 2 3/4", 6 oz., approx*

REMARKS *Operation Sequence No 3*

168 hrs per month

OPER. NO.	OPERATION	MACHINE	OPER TIME (MIN)	OCCUR PER PC	TOTAL MACH HRS. PER *Mo.*	NO. MACH REQ.
1	Face, Bore and Tap end	Turret Lathe	130	2	130	.78
2	Face, Bore and Tap top	Turret Lathe	140	1	70	42
3	Rough bore & Ream seat	2 sp Gang Drill	110	1	55	.33
4	Broach Hex Flats on end	Vertical Broach	1.00	2	100	.60

From Ireson, *Factory Planning and Plant Layout*, p. 22.

FIG. **8.10** MACHINE CAPACITY WORK SHEET USED IN COMPUTING MACHINE TIME REQUIRED FOR EACH PART.

be produced in a range of sizes, it may be possible to develop an efficient line by combining the times for the different sizes and allowing for the extra set-ups.

Figure 8.11 shows a summary sheet for a certain type of machine. On this sheet are summarized all the operations in the plant or division that require this kind of machine. A similar summary should be prepared for each type of machine.

The collection of summary sheets gives the *minimum* number of machines for the planned production by the *functional* layout method. It assumes continuous operation during the prescribed working hours and makes no allowance for scheduling difficulties or breakdowns. If any line-type layouts are to be used, and if they are not utilized for an equal percentage of the working time, additional machines will be needed. The consequences in terms of fixed costs can be computed for these extra machines and the decision on method of layout can be made on the basis of facts.

As the decisions regarding methods of departmentalization are made, an equipment list by departments should be compiled. Figure 8.12 shows a typical equipment list for a department. This example refers to an existing plant where all the equipment for the department is already owned. If new equipment is required, it would be added to the list and assigned a machine number. This

MACHINE CAPACITY REQUIREMENTS SUMMARY

MACHINE Turret Lathe SIZE OR CAPACITY 8' swing

NO. OWNED 5 MINIMUM NO. REQUIRED 8

SPECIAL FEATURES OR EQUIPMENT Chuck for Castings, Air Operated, 3-Jaw

REMARKS 168 hours per month

PART NO.	OPER. NO.	REQUIRED CAPACITY BY SIZES HOURS PER Mo.								TOTAL HRS. PER Mo	ESTIM. SET-UP TIME
		1/2"	3/4"	1"	1 1/4"						
157-B1	1	130	145	85	80					440	12
157-B1	2	70	80	52	48					250	12
157-B2	1	65	73	43	40					221	12
157-B2	2	70	80	52	48					250	12
	$\frac{1209}{168} = 7.2$	TOTAL REQUIRED PER MONTH								1161	48

From Ireson, *Factory Planning and Plant Layout*, p. 23.

FIG. **8.11** SUMMARY SHEET USED IN COMPUTING THE MINIMUM NUMBER OF MACHINES REQUIRED.

form serves a number of purposes. It is very useful at a number of stages in the development and installation of the new plan. It provides the specifications for the department and will help to assure that the facts are considered each time a decision is to be made. The form is completed in the following order:

1. Insert department name and number.
2. List machines, machine numbers, present location, services required, size, and weight.
3. Tabulate the services required in the appropriate spaces in heading.
4. Compute power required.
5. Enter product description.
6. Indicate materials-handling system, if known.

The space requirements are estimated (see Art. 5.4.3) and the location of the department is determined. (This may have been designated previously and the space may be a fixed amount.) After all tentative department locations have been decided:

EQUIPMENT LIST

DEPT. NO. D

DEPARTMENT Aluminum Specialties LOCATION: BLDG. #2

SPACE AVAILABLE Feb. 12, 19 PROD. TO START Feb 22 FLOOR 1st

SERVICE REQ. STEAM No POWER: AC - 3 Ph BAYS D-12,13,14

COMP AIR 100 P.S.I. CONNECTED LD. 25 KVA

GASES Natural gas VOLTAGE 110-220 DRAW. NO. L-145

WATER cold LIGHTING 110V - 6KW OTHER

PRODUCTS Misc. Alum Sheet Parts VOL. PER HR. 160 CU. FT, WT PER HR 300 LB.

MATERIALS HANDLING SYSTEM 4-wheel Hand truck and tote pans, Sheets by O-H Crane

EQUIPMENT	MACH NO.	PRES. LOC			AVAILABLE			DEST BAY	SERVICES REQ.	SIZE	WT	MOVE SCHED.	MOVE COMP
		BLDG	FL.	BAY	MO	DAY	HR.						
Squaring Shear-8'	S-10	#1	1st	B2	2	12	8A	D-12	220V Com Air	5'x13'x6'	5000	2-12 A	✓
Punch Press-10 ton	P-6	#1	1st	B3	2	13	8A	D-12	220V " "	3'x3'x7	1200	2-13 A	✓
Punch Press-10 ton	P-8	#1	1st	B-3	2	13	8A	D-12	220V " "	3'x3 x7	1300	2-13 A	✓
Press Brake-5'	P-2	#2	2nd	D12	2	15	12N	D-13	220V–	7'x4 x8	3,000	2-15 P	2-16 P
Hyd Press-200 ton	HP-4	#2	1st	D13	2	12	8A	D-13	220V-N Gas	—	—	No Move	✓
Press Brake-8'	P-10	#1	2nd	B3	2	14	12N	D-13	220V–	11x5'-9	5000	2-14 P	✓
Punch Press-Ind-25 ton	P-20	#1	1st	B-4	2	13	8A	D-12	220V Com Air	4'x4'x8	2600	2-13 P	2-14 A
Riveter - Auto	R-5	#2	2nd	C-5	2	12	8A	D-14	110V " "	2'x3 x5	500	2-12 P	✓
Riveter - Auto	R-6	#2	2nd	C-5	2	12	8A	D-14	110V " "	2'x3'x5	500	2-12 P	✓
Spot Welder-25 KVA	W-10	#1	2nd	C3	2	15	12N	D-14	220V " "	3'x6'x5	600	2-16 A	2-15 P
Arc Welder-200 amp	W-25	#1	2nd	C-3	2	15	12N	D-14	220V " "	4'x2'x3'	300	2-16 A	2-15 P

From Ireson, *Factory Planning and Plant Layout*, p. 66.

FIG. 5.12 TYPICAL DEPARTMENTAL EQUIPMENT LIST.

7. Specify location by building number, floor, and bays in the heading.

After the machine arrangement has been determined within the department boundaries (see Art. 5.5):

8. Insert the drawing number and the destination by bay for each machine.

9. Determine when machine will be available for move, and insert available date.

10. Prepare move and installation schedule, and insert date of scheduled move.

11. Check off the completion of the move, or insert the actual move date if it differs from the schedule.

5.4 DEPARTMENT LOCATION

5.4.1 Process departments. The relative position of departments within the building(s) is very important to the efficient operation of the plant. Several factors enter into this decision regardless of the method of departmentalization. These factors are:

1. Sequence of departments entered by products, and the amount of space needed for each department.

2. Nature of the processes involved. Are they hazardous, offensive, dirty, noisy, etc.?

3. Weight, size, and characteristics of machines. Floor load capacity, ceiling heights, space beneath floor.

4. Weight, size, and nature of products. Are they large and bulky, fragile, flammable, explosive, etc.?

5. Materials-handling costs. Does the arrangement minimize the movement distances, back-tracking, and crisscrossing?

6. Is this a service department that must serve a large area? Engineering, maintenance, production planning and control, inspection and quality control, raw stores, shipping, receiving, tool cribs, and maintenance.

7. Quality characteristics of the building space. Is this space noisy, dirty, poorly lighted, or poorly ventilated? Does it provide necessary work conditions such as security, crane ways, freedom from vibrations, docks, or wide bays?

8. Contacts with the public, and internal communication. Is it necessary for members of certain departments to have frequent visitors (the personnel department, for example), or frequent person-to-person conferences with members of other departments?

Each of these factors affects the efficiency of operations within the plant and directly or indirectly affects the overall cost of producing a given volume of work. It is possible to reflect the effects of many of these factors on costs in mathematical equations of varying complexity. If the effects of all factors are shown in one equation, the equation usually becomes very complicated and is difficult to solve for the minimum value. Many attempts have been made to establish mathematical models for this and similar problems, but none can be classified as completely satisfactory at this time. Smaller problems have been attacked by industrial operations research teams (see Section 15) with encouraging results. By limiting the departmental arrangement problem to include only a few factors, it is possible to obtain very good results.

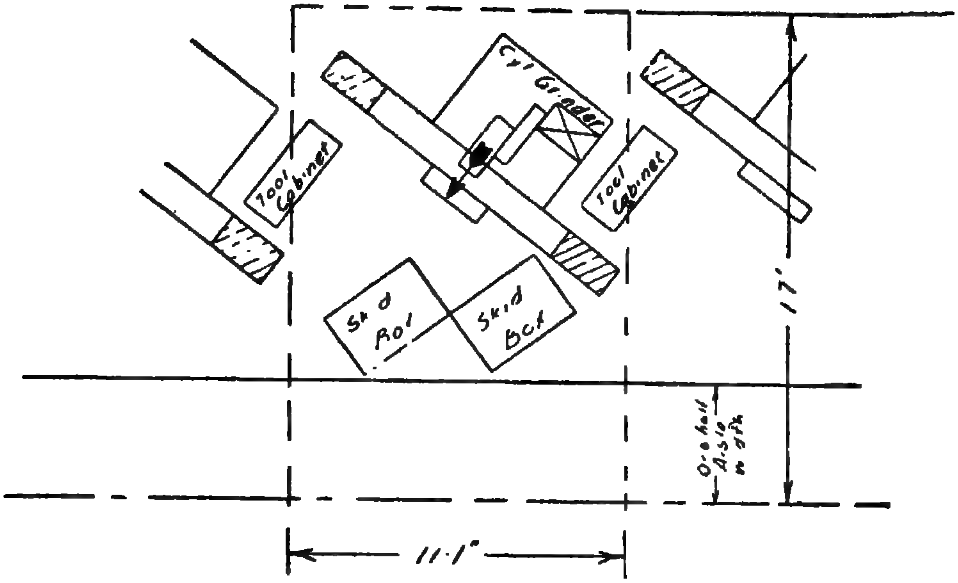
For the present, the problems must be solved by a combination of cost data, logic, and good judgment. Analysis of fixed factors will eliminate a great many possible arrangements and point out those that remain. (Refer to Art. 5.1.2.) For instance, the fact that the second floor of a building has a limited floor load capacity will eliminate the possibility of placing certain departments there. The location of rail sidings and truck docks fairly well establishes the location of receiving, raw stores, finished goods storage, and shipping departments. Examination of a collection of process charts may reveal that parts always start in one or two departments, and that certain other departments always follow each other in a fixed order. For example, the finish grind of precision parts may always (or usually) follow heat treatment. The fact that most of the tools issued to individual workmen will be used in a small number of fabricating departments will help locate the tool room for economy of workmen's time.

By establishing such limiting factors, the number of satisfactory arrangements can be reduced to a number small enough to be handled and tested for the optimum solution. If necessary, several different arrangements can be drawn to a small scale and compared. Criticisms and suggestions can be obtained from all levels of employees to help assure that all the alternatives have been recognized.

5.4.2 Line departments. The arrangement of line or product departments is commonly based upon the sequence of assembly of the parts, but this is not always practicable. Limitations, such as those enumerated in the previous paragraphs, may prevent such an arrangement. If the assembly line is to be fed by conveyors carrying the parts from the line departments, extra distance between the assembly and fabricating departments may not increase materials-handling costs substantially (see Art. 7). Thus, the use of conveyors by companies that enjoy volumes of output that justify them increases the freedom of locating the line departments; line departments can be located where they make the best use of the space available.

5.4.3 Estimating departmental space requirements. The space required for a department can be estimated by two different methods. The first method employs a ratio between the total space for the department and the space actually occupied by the machines and equipment. This ratio will vary with the type of layout, the type of industry, and the kind of machines involved. It commonly varies from 3:1 to 6:1. Each plant must conduct a study of its machines and operating conditions in order to arrive at a satisfactory ratio. This study can be made by surveying several existing departments that are considered to be typical of the plant. If the problem concerns a new plant, the planning engineers can prepare several layouts, using templates, and can compute the ratio.

The ratio method is most useful for estimating the space needed for line departments, since there will be several



From Ireson, *Factory Planning and Plant Layout*, p. 67.

FIG. **8.13** A TYPICAL PRODUCTION CENTER, INCLUDING SPACE ALLOWANCE FOR MACHINE, TOOL STORAGE, MATERIALS, MAINTENANCE AND AISLE.

different kinds of machines in each department. The department estimate is the product of the actual space occupied by the machines, and the ratio.

A second method employs the principle of the production center. A production center is composed of a single machine plus all the equipment and space required for its proper functioning. Ordinarily, this means that the center includes space for the machine, the tool cabinet, worked and unworked parts, access to the aisle, operator space, and maintenance space around the machine. Figure 8.13 shows a typical production center. After the production center is designed, its space requirement is multiplied by the number of machines in order to obtain the departmental space estimate. It is obvious that this method is most useful in estimating the space for process departments. Furthermore, the dimensions of the production center provide a basis for establishing the most efficient dimensions for the department. Access aisles are usually included in the production-center estimate, but main traffic aisles are not, and must be provided when locating the department boundaries on the building floor plan.

There is more likelihood of errors in the space estimates from the ratio method than from the production-center method. Therefore, it may be necessary to make slight adjustments in the departmental boundaries when the machine layout is planned (see Art. 5.5). Also, if growth is expected in the immediate future, space for additional machines may be provided in the original plan, and the present machines may be arranged so that the new machines can be installed without disturbing the other machines. This space must be included in the original estimate.

5.5 MACHINE LAYOUT

The arrangement of the machines within the departmental boundaries is made after the location of the department has been established. There are three common methods of planning this arrangement:

1. Drafting or sketching.
2. Two-dimensional templates.
3. Three-dimensional models.

5.5.1 Drafting or sketching machine arrangements. The preparation of a

machine layout by this method usually requires a certain amount of preliminary work. The draftsman or planning engineer, working from the equipment list and on a scale drawing of the department space, establishes in his mind the basic pattern of the layout that he thinks will be satisfactory. He probably will make a few free-hand sketches, approximately to scale, showing the general position of the several machines, and obtain comments from his associates on the plan. After examining it from all viewpoints, he may prepare another free-hand sketch, or he may start drafting the layout on tracing paper or cloth. He actually makes a top view of each machine in its proper position relative to other machines, conveyors, columns, windows, and so on. He will usually work in pencil so that he can make changes with ease. The drawing is presented to management and other interested persons, and comments or approval are obtained. It is common for such a plan to be revised two or more times before it receives final approval.

It is obvious that such a method of determining machine layout can become very expensive if more than one or two revisions are required. There are instances, however, where this method is probably the most economical and perfectly satisfactory. The conditions that are favorable to this method are:

1. Process departmentalization.

2. A large number of similar machines or pieces of equipment in each department.

3. Ample floor space, with no major incentive to arrange the equipment in the smallest possible space.

Since process departments are arranged to accommodate a variety of products, more space is usually allowed around the machines than in a line department. If a satisfactory production center has been designed for the type of machine to be used, the layout consists primarily of repeating this production-center layout as many times as is necessary. Thus, the real work is done in designing the production center. Once that has been approved, there is little likelihood that the departmental arrangement will not be approved. This means that the layout should be accomplished with few revisions.

The draftsman can simplify his work by preparing a cardboard or plastic template of the production center and using it as a guide for drawing the outlines of the machines, tables, conveyors, boxes, and so on.

The drafting method can usually be used quite satisfactorily for the layout of drafting rooms, clerical or typographical offices, insurance companies, banks, functional departments, packaging, inspection, and many others.

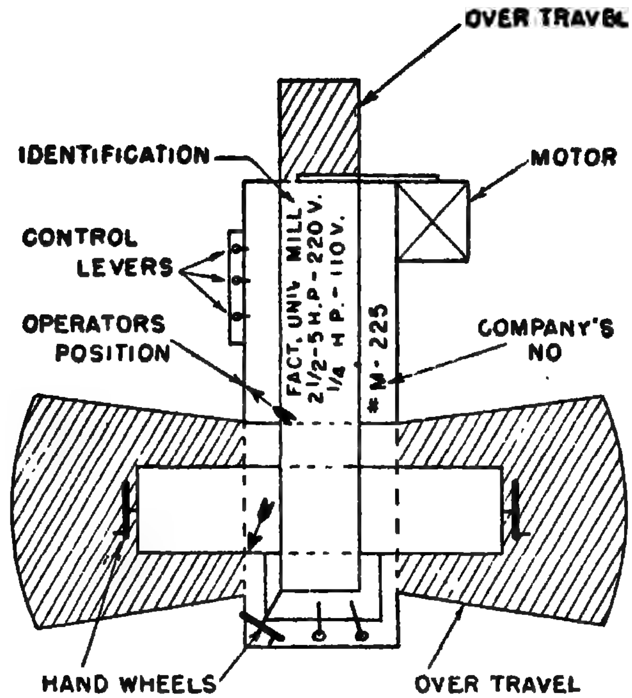
5.5.2 Two-dimensional templates. The two-dimensional template is simply a piece of some flat, stiff material on which is shown a projection of the machine and its over-travel and/or stock over-hang to scale. It is then cut out of the material along the extreme outlines. The two-dimensional template is the most popular of the methods used and is the one that is most likely to give the best machine arrangement with the smallest over-all cost of planning. The template method of layout has become so popular that the American Society of Mechanical Engineers has published a standard for templates and models.* This standard presents the most acceptable practice on material for templates, scale, representation of machine features, over-hang and over-travel, and identification. A summary of the most important characteristics follows:

1. The template should be made of heavy cardboard, plastic, or fiber that can be used repeatedly without serious wear or soiling and that will lie flat.

2. The material of the template should take ink or some other convenient marking material.

3. The template should be a projection of the machine and *all* over-hang and over-travel of machine parts, work, carriages, and so on; the machine base should be outlined on templates.

* *Plant Layout Templates and Models—1949* (New York: The American Society of Mechanical Engineers, 1949).



From Ireson, *Factory Planning and Plant Layout*, p. 81.

FIG 8.14 A TYPICAL TEMPLATE FOR PLANT LAYOUT PURPOSES. NOTES INDICATE THE INFORMATION DESIRED AND THE SYMBOLS USED.

4. An agreed-upon set of symbols should show the location of motor, control levers, handwheels, and work.
5. The template should be capable of being photographed in black and white without losing any essential details.
6. The template must contain some form of identification.
7. The scale should be $\frac{1}{4}'' = 1'0''$.

A template of a milling machine is illustrated in Fig. 8.14.

Since the preparation of suitable templates by ordinary drafting methods is rather inefficient and costly, a number of companies have developed other methods of producing templates commercially and offer them for sale to using companies. Most of the commercial templates use clear plastic of various thicknesses as the basic material and provide means for attaching the templates to the tracing of the plant area. Some use pressure-sensitive cement and others use alnico magnets for this purpose. In some cases, the template is flexible and can be run through blueprint or Ozalid machines; others are stiff and the print paper must be exposed by placing strong lights above the layout on a flat surface.

The great advantage of clear plastic templates of all types over cardboard or fiber is that the internal lines, symbols, and identification information are recorded on the blueprint at the same time as the outlines are recorded. If opaque templates are used, the information must be lettered or typed within the machine outline after the print has been made. The ease with which the clear plastic templates can be removed and rearranged, and the ease with which a record of each trial can be made, encourage planning engineers to try several different layouts before reaching a decision. The results of the different layouts can be compared critically only if a record is made of each one.

Most of these templates will function properly on regular tracing paper, but a number of suppliers also provide thin plastic sheets to replace the tracing paper or cloth. These plastic sheets are printed or scored in quarter-inch squares so that the templates can be oriented

with respect to columns, walls, and other machines simply by counting squares. The building outlines, columns, windows, conveyors, aisle boundaries, over-head monorails, stairs, flow lines, and so on, are printed on translucent, pressure-sensitive tape and are applied directly to the plastic sheet to provide a complete drawing of the building area. Thus the complete layout and as many prints as desired can be made without drawing anything.*

5.5.3 Three-dimensional models. Three-dimensional models provide the most realistic means of representing the equipment of a plant, and in many ways makes the machine arrangement easier to accomplish. These are scale models of the machines and equipment, with as much detail incorporated into them as their size will permit. The scale is customarily ¼″ = 1′ 0″, which corresponds to the most frequently used scale for two-dimensional templates, and permits the use of the same blueprints or tracings of the factory building. Models do not ordinarily show over-travel or over-hang of work, but do show tables, carriages, and controls in their normal position.

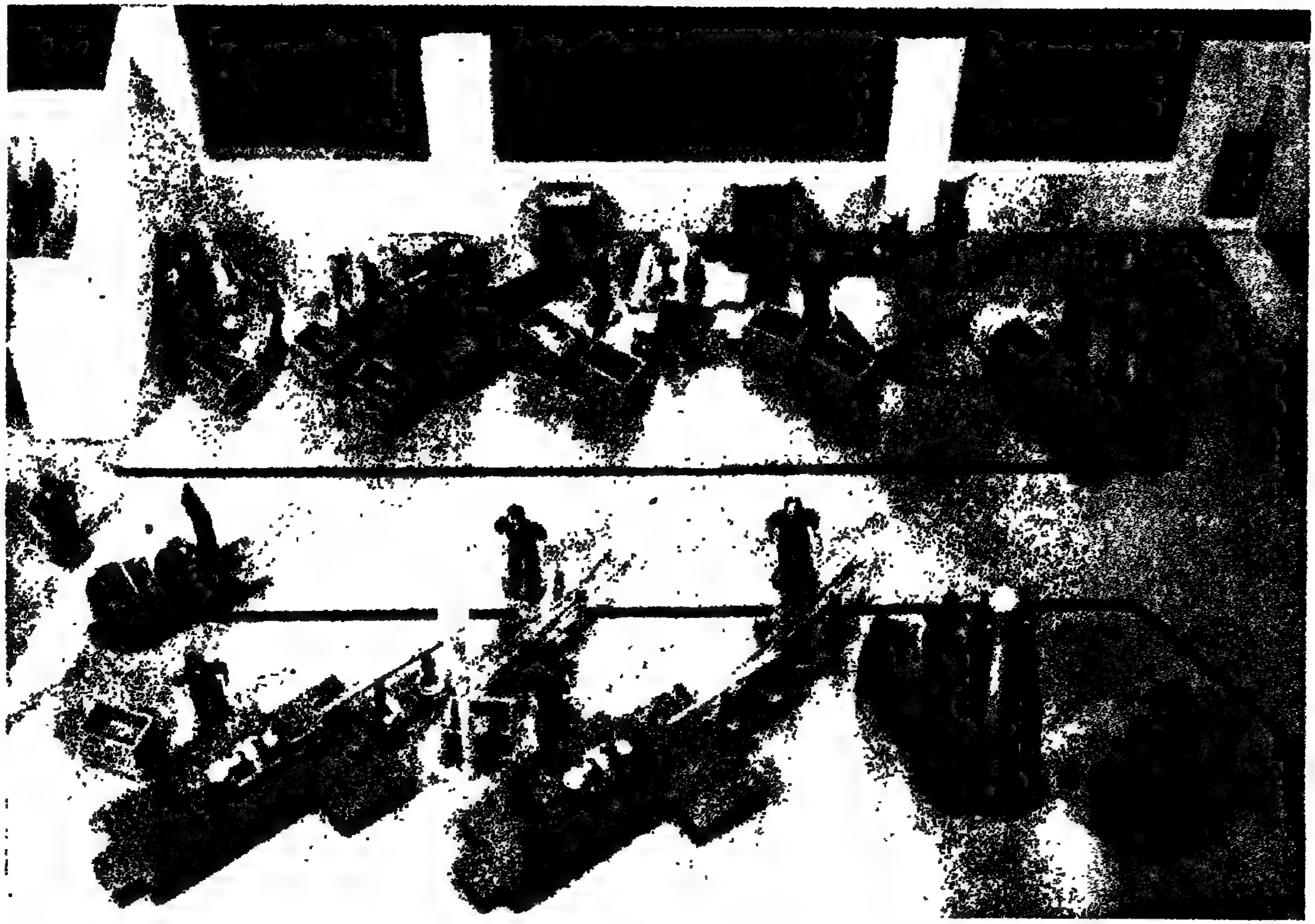
Models should be made of a material that will withstand frequent handling and even dropping. They should be heavy enough to stand upright even in a light breeze. They should be painted according to a color code, such as that used by the Air Force or recommended by the Du Pont Company or the Pittsburgh Plate Glass Company. In addition to the usual colors for the machine base, points of danger, moving parts, and so forth, the machined surfaces are usually painted with an aluminum or white paint. The color code adds to the realism of the model, but, what is more important, the planning engineer can tell more about how to arrange the machines in order to provide for safe working conditions, ease of handling work, position relative to light source, and so on.

Although models are relatively expensive in first cost, they frequently save their cost in the first re-layout problem by saving time for everyone concerned, from the workmen through top management. The use of models makes it unnecessary to be able to read blueprints in order to understand a proposed layout. Anyone can grasp the essential characteristics of the proposed layout more quickly from seeing the three-dimensional model than from seeing a two-dimensional blueprint of the same layout. Thus the ideas of many persons can be brought to bear on the problem with a minimum loss of time. The models have a certain visual appeal, for most persons in a plant will stop and shift models around on the plan when they would not give a blueprint a second look. Even experienced layout men usually find it easier to visualize all the difficulties of a layout problem by using a model.

Just as with two-dimensional templates, it is important that a record be made of each different proposal so that all proposals can be compared objectively. Since the models do not lend themselves to blueprinting, the only practical method lies in photography. Figure 8.15 shows a photograph of a small section of a plant model. Obviously, it would be difficult for the millwrights to work from such a photograph in installing the machines. A grid on the floor of the plant model would help considerably. One solution of this problem lies in using both two-dimensional templates and three-dimensional models. In this method, the arrangement is made by using the models on the tracing or plastic sheet. When the arrangement has been perfected, each machine is replaced by a plastic template secured to the tracing in exactly the same position. One or more blueprints are then made, and another proposed arrangement can be set up. In

* These products are available from such companies as:

Magne-PlasTic Corporation, 79 North Gratiot Ave., Mount Clemens, Michigan; F. Ward Harman Associates, Halesite, L. I., New York; Repro-Templets, Inc., Oakmont (Allegheny Co.), Pennsylvania.



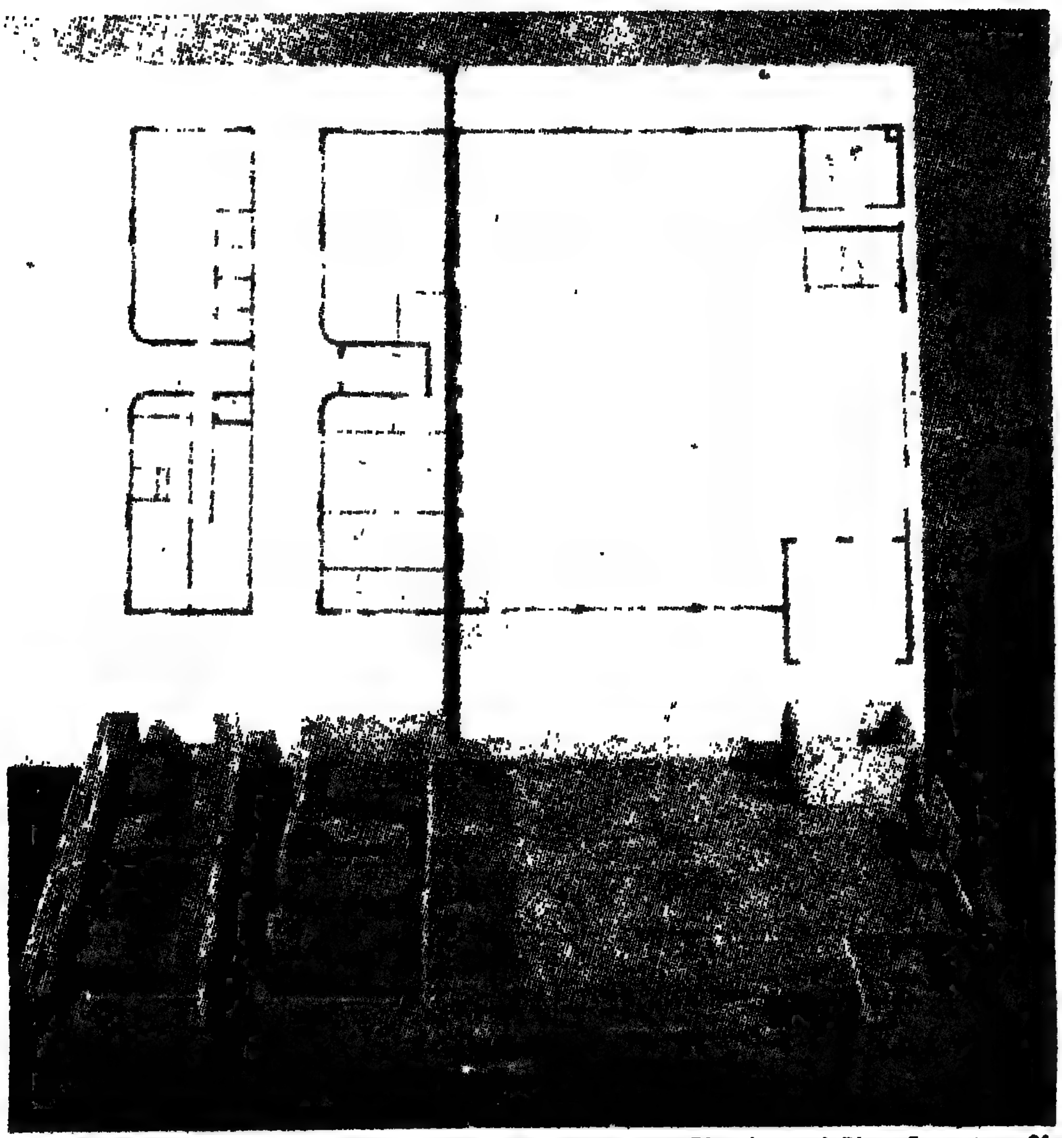
From Ireson, *Factory Planning and Plant Layout*, p. 101.

FIG. **8.15** PLANT LAYOUT USING MODELS OF BOTH EQUIPMENT AND BUILDING.

this way, the advantages of both methods are obtained, but the costs of both methods are also involved.

Storage of three-dimensional models of plant buildings and machines presents a problem of major proportions for a large concern. The model of the building is the most difficult, for it may be so large that rearranging the machines in certain areas requires the layout men to work from a temporary bridge constructed over the model. This naturally increases the difficulty of keeping the model up-to-date. One solution dictates that sectional planning boards of some convenient size, such as 24 by 36 inches, be used in place of a plant model. The blueprint or tracing of the plant area is divided into pieces of the same size which are mounted on the boards. These are usually covered with a plastic sheet to provide a good working surface. These boards are identified along the edge and are stored horizontally in a closed cabinet. Two or more sections can be removed for study or re-layout when needed. If desirable, all boards can be placed in their proper position to show

FIG. 8.16 THREE-DIMENSIONAL SCALE MODEL OF A FACTORY BUILDING AND THE LAYOUT OF THE SAME BUILDING ON TWO SECTIONS OF PLANNING BOARDS.



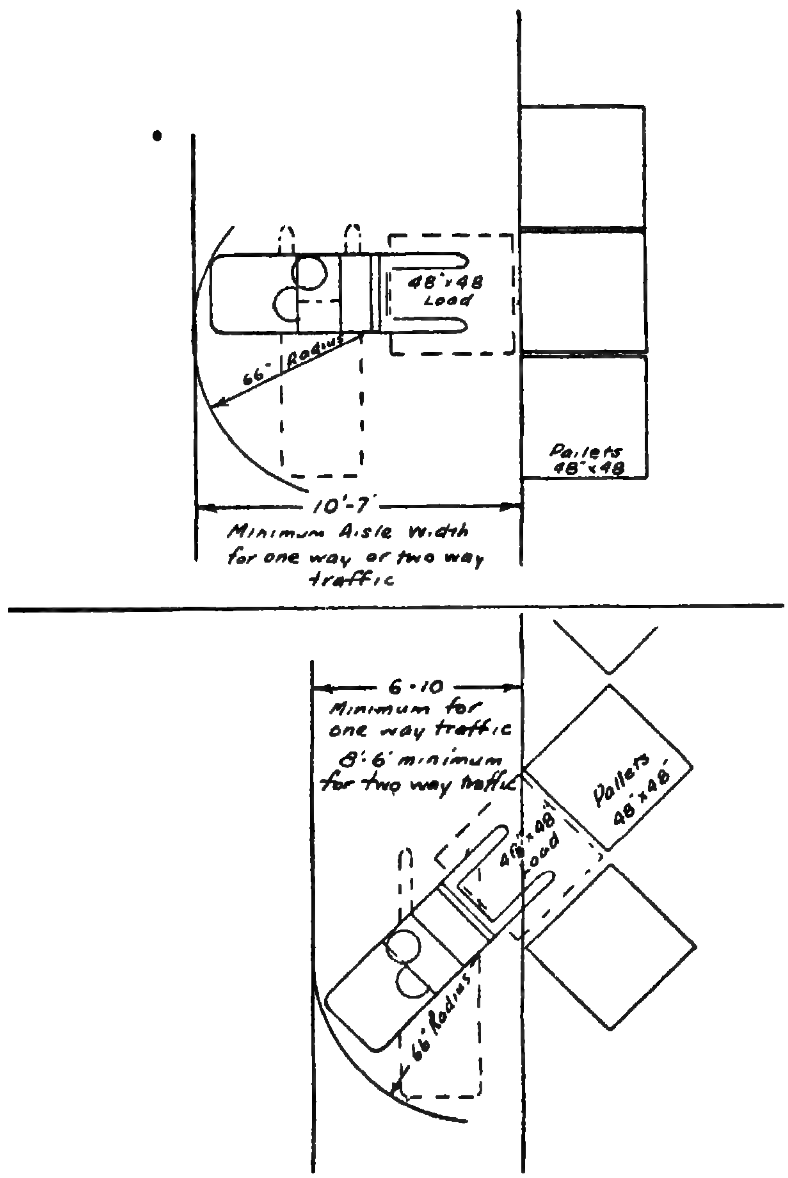
From Ireson, *Factory Planning and Plant Layout*, p. 94.

the complete plant plan, floor by floor. Figure 8.16 compares a scale model of a small plant building with the two corresponding sectional planning boards. The models of the machines and equipment can be attached to the boards and stored as a permanent record of the plan and as a constantly available tool for use in replanning the area.

5.5.4 Aisles. Aisles are highways over which both materials and personnel must travel; the width and arrangement of aisles can be set only in relation to the kinds and volume of traffic that must be handled. The layout engineers can base the aisle width and location on the following variables:

1. Size and kinds of trucks and turning radii (power or manual).
2. Size of load to be carried by each type.
3. Frequency of trips.
4. Frequency and volume of personnel traffic.
5. Boundary conditions (location of machines and other items along aisles).
6. Method of picking up and depositing load and position of load relative to aisle.
7. One-way or two-way traffic.

FIG. **8.17** A STUDY OF THE EFFECTS OF PALLET POSITION ON THE WIDTH OF AISLES.



From Ireson, *Factory Planning and Plant Layout*, p. 118.

8. Are individual machines to be served by aisles, or are only designated areas adjacent to a group of machines to be served?

Figure 8.17 illustrates how the position of the load, the size of truck and load, and one- or two-way traffic affect the aisle widths.

A tabular illustration of aisle widths established for a machine shop, where each machine was served and where each machine or piece of equipment was at least one foot from the aisle boundary, is shown at the bottom of this page.

Aisles should not be excessively wide, and should not have too many turns or obstructions. Turns, obstructions, and blind corners invite accidents, and excessively wide aisles invite use as temporary storage areas. Careful planning of aisles will reduce handling time, improve service and utilization of materials-handling equipment, and help prevent personnel injuries and damaged materials.

5.5.5 Storage areas. A substantial portion of the floor space of every industrial plant is devoted to the storage of raw materials, tools, supplies, work-in-process, subassemblies, and finished goods. Careful planning of both the location and layout of storage facilities can reduce the time for controlling and issuing materials, costs of materials handling, loss or damage to materials, and direct labor time. Since each company's storage problems differ to some extent, no rules can be given that will apply in every case. However, the following principles can be used as guides in arriving at an economical arrangement:

1. Decentralize storage areas to conserve workmen's time spent in securing supplies, but keep each storeroom large enough to keep one stores clerk reasonably occupied.

2. Do not put bulky items (those that are not easily pilfered) in inclosed storerooms unless special storage conditions are required for safety or to prevent deterioration.

3. Try to store bulky items at the point of use to prevent rehandling.

4. Consider the cost of exerting complete control over stores against the probable cost of stolen or misplaced items and the inaccuracies that will occur in cost accounting.

5. Attempt to arrange storage areas according to classes of items in order to prevent unnecessarily large inventories through duplication.

6. If materials are stored at point of use, make the workmen responsible for notifying purchasing when stocks are reduced to some specified quantity.

7. Plan storage areas so that mechanical handling equipment can be used

Truck traffic	*Frequency: trips per hr.*	*Maximum width of load*	*Pedestrian traffic*	*Safety clearance*	*Width selected*
One-way fork trucks	15-20	4 ft	infrequent	2 ft	6 ft
Two-way fork trucks	15-20	4 ft	frequent—workers carry light load	4 ft	12 ft
Tractor and one to four 8′ trailers, one-way	8-12	4 ft	infrequent	3 ft on straight aisle 5 ft on curves	7-9 ft
Tractor and one to four 8′ trailers, two-way	8-12	4 ft	infrequent	5-7 ft	13-15 ft
Two-way, manually operated, warehouse two-wheeled truck	20-30	2½ ft	frequent	2 ft	7 ft

to the maximum advantage. Handle as little as possible by hand.

8. Classify all materials, tools, subassemblies, and so on, according to some standard classification, and arrange storage facilities by classifications so that any item can be located quickly and easily.

9. Permanently allocate space, bins, racks, or shelves to standard and regularly stocked items, based upon probable maximum quantities of each item.

10. Select storage equipment for the specific storage problem.

11. Employ vertical space to conserve floor space by using stacking pallets, bins, skid boxes, and mezzanine floors.

12. Observe safety codes when planning storage facilities for hazardous materials.

5.5.6 Planning personnel facilities. It has been recognized in recent years that the attitudes of factory personnel are extremely important to successful operation. The physical facilities to care for personnel needs directly affect the workers' attitudes and should be planned as carefully as the production facilities. The workers' physical comfort, morale, and loyalty to the company are reflected in his productivity and affect the direct labor, materials, and burden costs of production. The planning engineers should make specific provisions for employee facilities at the same time as they are planning the production facilities. The most frequently provided personnel facilities include adequate provisions for the following:

1. Employment interviewing, testing, physical examinations, assignment to job, training, and upgrading.
2. In-plant medical service, dispensaries, and first aid.
3. Comfortable working conditions relative to heat, light, noise, humidity, dirt, dust, and fumes.
4. Lockers, washrooms, and toilets.
5. Food service.
6. Recreation facilities and programs.
7. Special services:
   a. Loans and banking.
   b. Union activities.
   c. Insurance programs.
   d. Legal, income tax, and similar services.

Almost all plants make some provisions for the first four items above. The community facilities, union demands, type of employees, number of employees, availability of suitable labor force, management attitudes, and employees' desires will largely determine the extent to which personnel facilities will be provided beyond the bare minimum. Modern management is in general far exceeding the bare minimum because it has recognized the advantages of a friendly, loyal, and cooperative work force. Companies that have employed more progressive programs, and that have thereby convinced the employees that management is genuinely concerned over their welfare, have enjoyed peaceful employee relations and long periods of uninterrupted production. Eastman Kodak Company and the Lincoln Electric Company are notable examples.

The space for personnel facilities should be determined according to the number of employees in each division or section of the plant. The principal services requiring space within the factory areas are those that are used frequently each day by the employees: washrooms, toilets, lockers, water fountains, and food services. First-aid and medical service, though not used daily by large numbers of employees, must be conveniently located within the factory in order properly to serve its function. Table 8.2 gives the minimum number of water closets, urinals, and wash basins required by the New York State Labor Code. Since these are minimum requirements, they should not be considered the most desirable quantities. Usually, they should be increased by 20 to 40 per cent. The numbers should also be used for floors, divisions, or sections of the plant rather than for the whole plant. Thus, 400 persons equally distributed over four divisions or floors should be treated as four separate problems, and provisions for 100 persons should be made in each division.

After the number of units to be provided in each division has been deter-

SECTION III: MINIMUM FIXTURE REQUIREMENTS (NEW YORK STATE LABOR CODE) *

Number of men	*Water closets*	*Urinals* ‡	*Number of women*	*Water closets*	*Number of men or women*	*Wash basins* †
1-9	1	0	1-15	1	1-20	1
10-15	1	1	16-35	2	21-40	2
16-40	2	1	36-55	3	41-60	3
41-55	2	2	56-80	4	61-80	4
56-80	3	2	81-110	5	81-100	5
81-100	4	2	111-150	6	101-125	6
101-150	4	3	151-190	7	126-150	7
151-160	5	3	191-240	8	151-175	8
161-190	5	4	241-270	9	176-205	9
191-220	6	4	271-300	10	206-235	10
221-270	6	5	301-330	11	236-265	11
271-280	7	5	331-360	12	266-295	12
281-300	7	6	361-390	13	296-325	13
301-340	8	6	391-420	14	326-355	14
341-360	8	7	421-450	15	356-385	15
361-390	9	7	451-480	16	386-415	16
391-400	10	7	481-510	17	416-445	17
401-450	10	8	511-540	18	446-475	18
451-460	11	8	541-570	19	506-535	20
481-520	12	9	601-630	21	536-565	21
521-540	12	10	631-660	22	566-595	22
541-570	13	10	661-690	23	596-625	23
571-580	14	10	691-720	24	626-655	24
581-630	14	14	721-750	25	656-685	25
631-640	15	15	751-780	26	686-715	26
641-660	15	12	781-810	27	716-745	27
661-700	16	12	811-840	28	746-775	28
701-720	16	13	841-870	29	776-805	29
721-750	17	13	871-900	30	806-835	30
751-760	18	13	901-930	31	836-865	31
761-810	18	14	931-960	32	866-895	32
811-820	19	14	961-990	33	896-925	33
821-840	19	15	991-1020	34	926-955	34
841-880	20	15			956-985	35
881-900	20	16			986-1015	36
901-930	21	16			1016-1045	37
931-940	22	16			1046-1075	38
941-990	22	17			1076-1105	39
991-1000	23	17			1106-1135	40
					1136-1165	41

* From *Washroom and Locker Room Facilities*, Policyholders Service Bureau, Group Division, Metropolitan Life Insurance Company. Reproduced by permission. Reprinted from Ireson, *Factory Planning and Plant Layout*, Appendix C, p. 374.

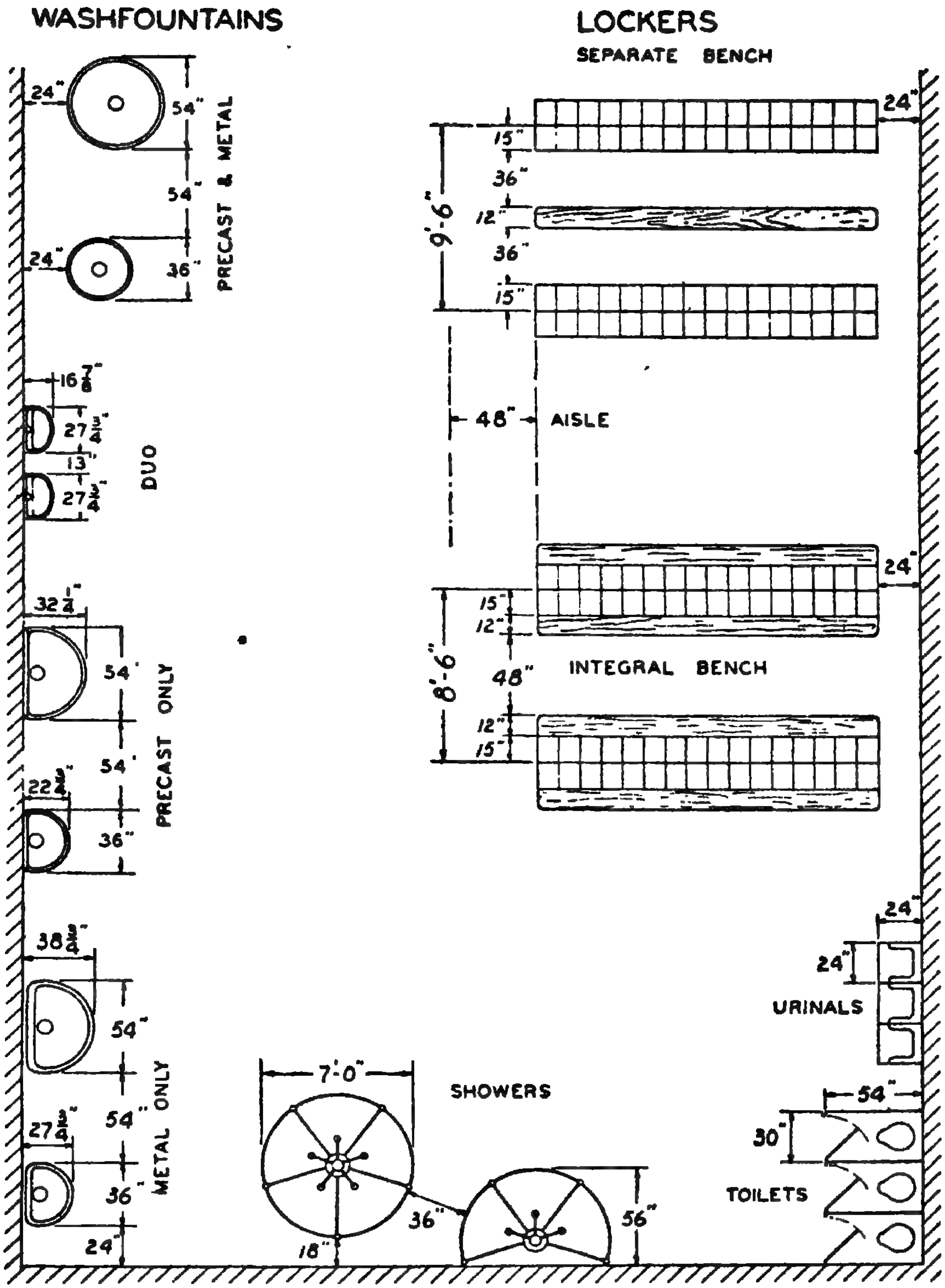
† 20 inches of wash trough with a faucet equals one basin.

‡ 24 inches of slab urinal is equivalent to one individual urinal.

"In all factories where lead, arsenic, or other poisonous substances, or injurious or noxious fumes, dust, or gases are present, resulting from trades or processes which have been declared dangerous by the Industrial Board, the washing facilities shall include separate washrooms for males and females, and not less than one (1) wash basin or its equivalent for every ten (10) employees, with running hot water, soap, and individual towels. Either paper towels or an adequate daily supply of clean towels shall be supplied."

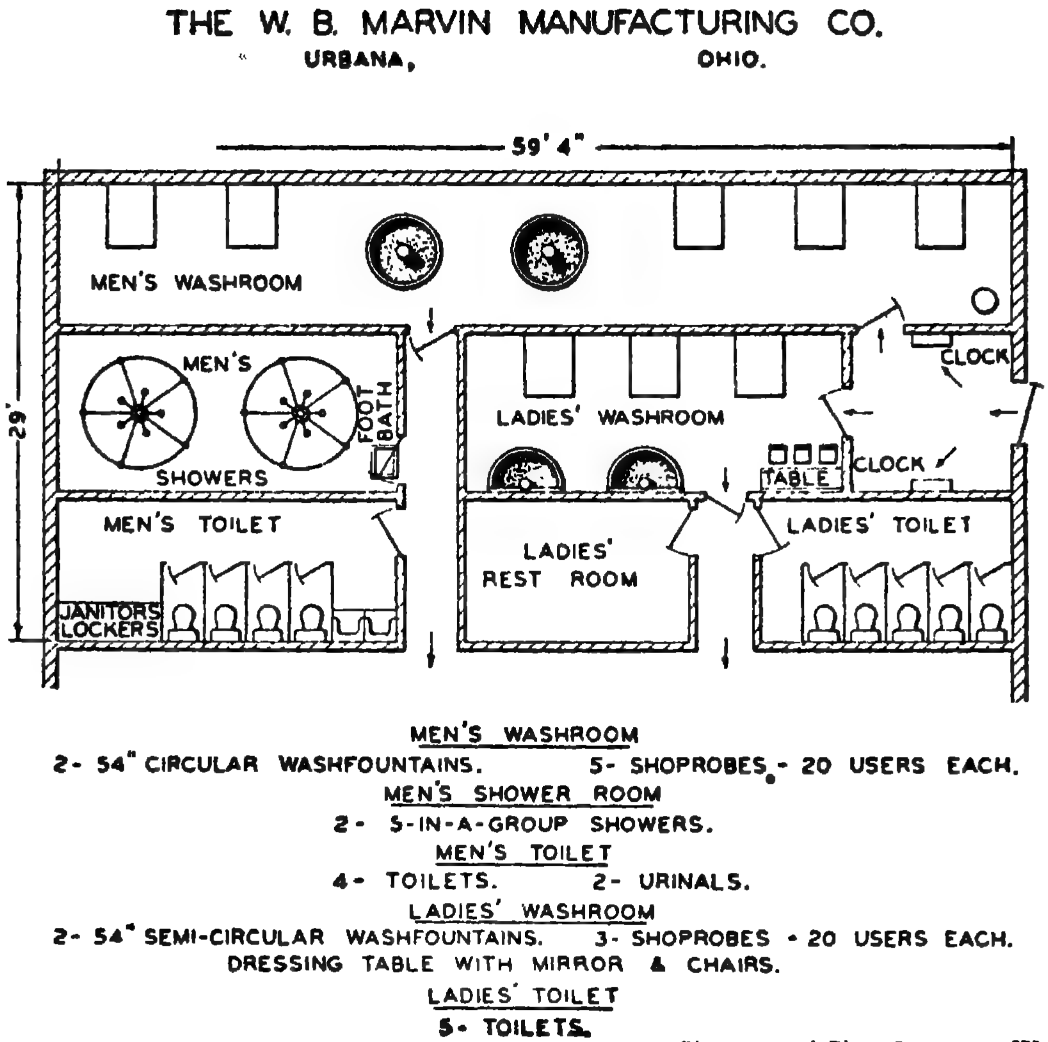
mined, the space requirements can be estimated from the information in Fig. 8.18.

First-aid and medical service space depends upon the type of service to be rendered. Company policy regarding medical service beyond the minimum first aid required will dictate the number of offices for nurses, doctors, examinations, and treatments. As the medical



From Ireson, *Factory Planning and Plant Layout*, p. 373. Courtesy Bradley Washfountain Company.

FIG. 8.18 MINIMUM PRACTICAL CLEARANCES FOR WASHFOUNTAINS, SHOWERS, TOILETS, AND LOCKERS.



Factory Planning and Plant Layout, p. 275.
Courtesy Bradley Washfountain Company.

FIG. **8.19** PROPOSED TOILET FACILITIES FOR COMPANY EMPLOYING UP TO 100 MEN AND 60 WOMEN.

service is extended to the families of employees, the facilities must be expanded even more. Some companies maintain complete hospitals for use by the employees and their families. Very few standards exist by which the space and facilities for a given service can be estimated, but the standards on p. 595 are recommended as a guide to the service to be provided.

The medical office should be readily accessible to the employees and also to the employment office. Figure 8.24 shows one plan for the arrangement of medical facilities on the first floor of the office building for a multi-building plant (see also Section 12, Industrial Hygiene).

Company-sponsored food service has become a standard practice in most industries. Even the very small plants usually provide some simple food service, such as hot coffee and cookies or doughnuts during the working hours and space for a food vendor to sell sandwiches and beverages during the lunch period. A sufficient quantity of nourishing food is essential to the well-being of the employees, and many companies subsidize the food service substantially in order to encourage the employees to eat wholesome meals. It is an accepted principle that company food service should provide comparable meals at lower cost to the employee than commercial establish-

Number of employees per shift	Medical Service Provisions
25 or less	One first-aid station, at least two persons trained in first aid, and a contract for professional service with a local doctor.
26-100	Two to three first-aid stations, six to ten persons trained in first aid, and contract with local doctor.
101-200	One full-time nurse, nurse's office equipped for routine examinations, complete first aid, couch, sterilizer, medical supplies, etc. Contract with local doctor to care for professional needs and to spend a certain amount of time at the plant for examinations. Three to four emergency first-aid stations throughout plant, with 10 to 20 persons trained in first aid.
201-400	A full-time nurse and a half-time doctor. A completely equipped office for the doctor, an examination room, and an office or treatment room for the nurse. First-aid stations throughout plant.
401-600	A full-time nurse and a full-time doctor. The same equipment as in the case of 201 to 400 employees.
601-1,000	Two full-time nurses and one full-time doctor. Same equipment, except two treatment rooms should be provided.
over 1,000	One doctor and two nurses for 1,000 to 1,200 employees.

ments can provide. This means that the company must not try to recover from the sale of the food such items as rent on the space, power, heat and light, building maintenance and, in some cases, even the cost of preparation.

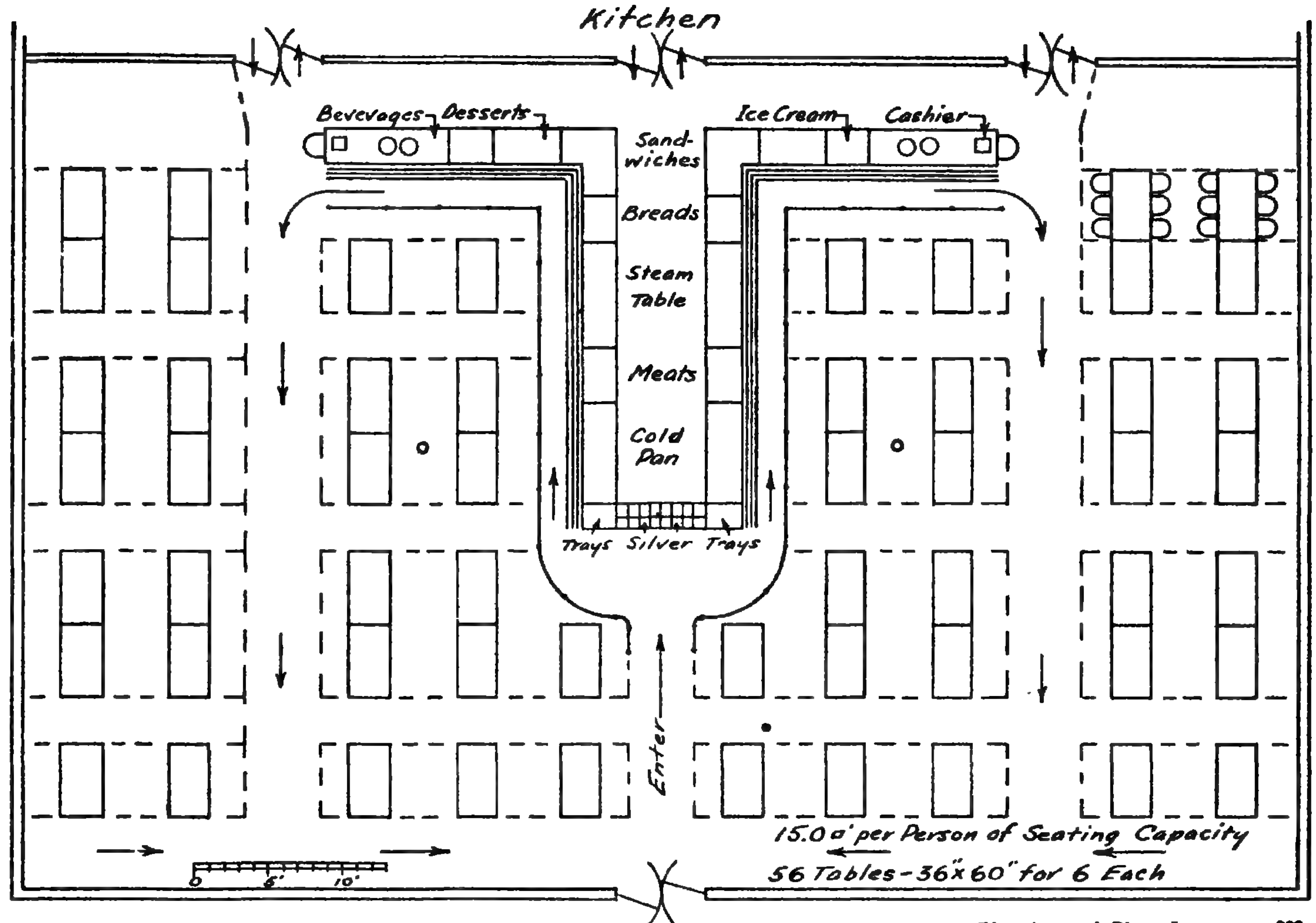
The types of food service commonly provided in plants of different sizes are:

1. A coffee bar.
2. A rolling cafeteria.
3. A small diner.
4. A lunch counter.
5. A cafeteria.
6. A restaurant with table service.

The most important considerations in planning food service are:

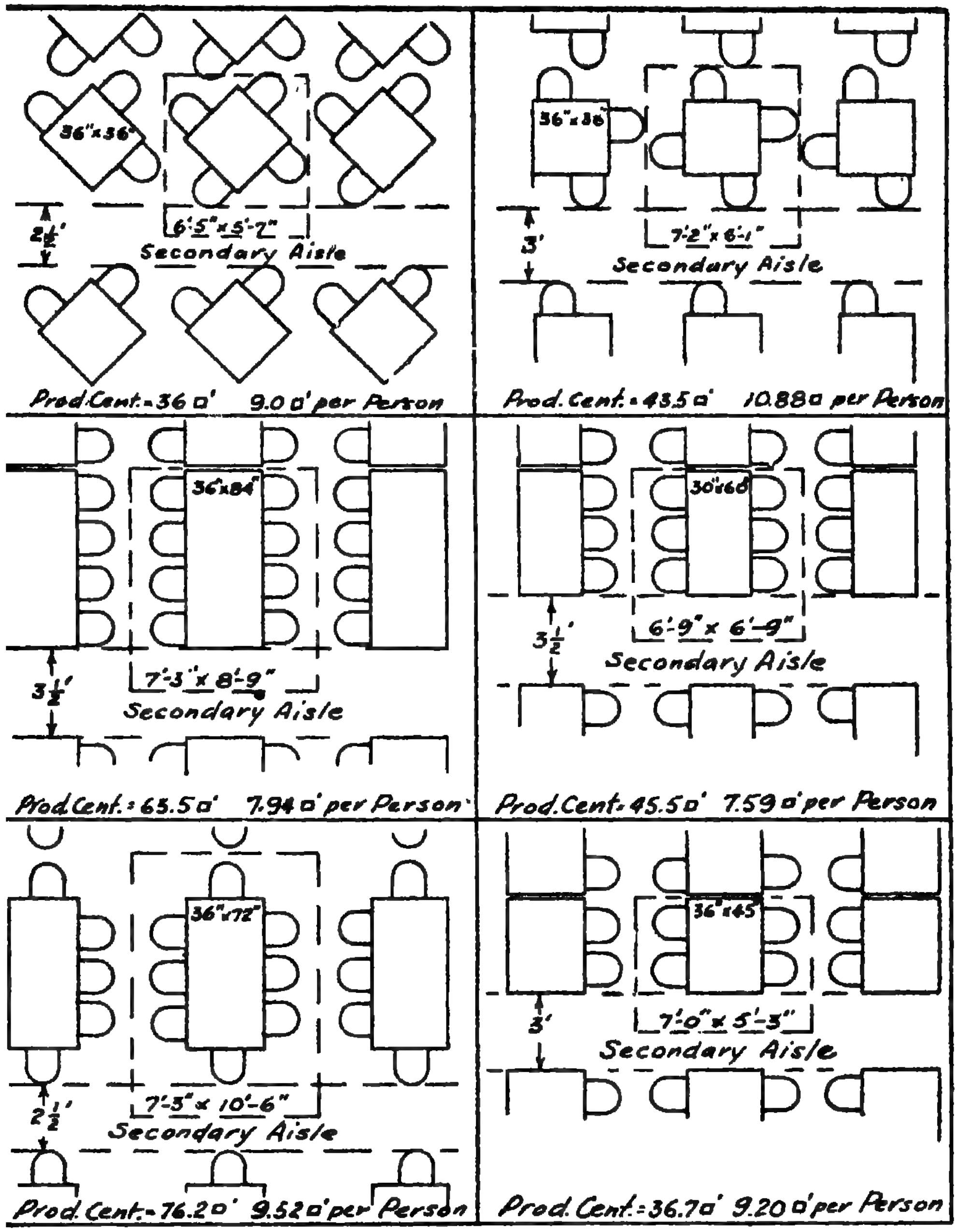
1. Service must be fast so that employees will not have to wait and then eat rapidly.
2. The food service area should be located conveniently to the work areas of the majority of the employees.
3. The lunch period should be long enough to enable the employees to reach the service area, eat slowly, and return to work stations without rushing.
4. The eating habits of the employees should be considered in selecting kinds of food to serve. (Do not try to force employees to eat strange food.)
5. Variety of food should not be so great as to increase preparation expense unnecessarily or to increase the time required by the employee to make his choice.
6. The service should be planned to provide for continuous serving over a period of one and a half to two hours by staggering the times of the lunch periods.
7. An ample quantity of good quality is better than smaller portions of the best-quality foods. Preparation should be thorough.
8. Plan food service areas so that they can be used for other purposes when food is not being served. (Conference, recreation, or training space.)
9. The food service area should be exceptionally clean and pleasant. (It should be light, colorful, relatively quiet, and lend an atmosphere of relaxation to the lunch period.)

Figure 8.20 shows a cafeteria planned to provide maximum seating capacity and service capacity within a limited



From Ireson, *Factory Planning and Plant Layout*, p. 282.

FIG. **8.20** CAFETERIA PLAN FOR FEEDING 200 TO 300 EMPLOYEES SIMULTANEOUSLY.



From Ireson, *Factory Planning and Plant Layout*, p. 283.

FIG. 8.21 A STUDY OF TABLE SPACING FOR INDUSTRIAL RESTAURANTS BY PRODUCTION CENTER METHOD.

space. It is arranged to keep the traffic flowing in two large circles with minimum interference.

Seating space is the principal space problem in food service. Figure 8.21 provides a graphical comparison of the space required to seat a person, using several sizes of tables and different arrangements. It should be noted that the values in square feet per person are only for the actual seating space, and do not include main aisles, serving facilities, or kitchen areas. Hotel and restaurant supply houses are always glad to provide professional assistance in planning the food service for a plant. They will provide complete listings of the kitchen, dish-washing, and serving equipment, and in some cases will actually prepare layouts to fit the specific space available.

Offices in which other personnel services are conducted should be located according to the amount of contact with the individual employees. Any services that require person-to-person communication with the employees should be conveniently located to the plant entrances or work areas. Such an arrangement will encourage the employees to use the service and will help to reduce the traffic through other office areas. Offices for services that are conducted by mail or intra-plant memo can be located without reference to the employee entrances. For example, payroll reductions for U. S. Bond purchases, life insurance, repayment of loans, or union dues can be made in the regular payroll offices.

State and city codes must be observed in determining what personnel facilities and services will be provided. Most states have labor codes covering the minimum number of washroom and toilet facilities, ventilation and cleanliness of facilities, inspection of food service facilities, first-aid and medical services, workmen's compensation, employer liability, and hours and conditions of employment for women and children. The planning engineers should become thoroughly familiar with the appropriate code before planning any personnel facilities and should be sure that all requirements are satisfied by the plans. In most cases, the codes should be interpreted as minimum requirements, and further investigation should be made to determine suitable facilities for both immediate and future needs. Provisions should be made for expansion of the facilities as growth occurs, even though the extra facilities may be just roughed-in now and completed later as needed.

5.5.7 Criteria of effective layout. There are no real *standards*, such as thermal efficiency, length, weight, or speed, by which the effectiveness of a plant layout can be measured. The criteria by necessity must be by comparison of costs of performing certain functions by different plans. Over-all costs of producing a given quantity of goods of a certain quality and within a certain time period then become the means for determining the best plan of those proposed. How nearly the optimum plan is obtained depends upon the ingenuity of the planner and the thoroughness with which he performs the analyses of the data available. The objective of the previous articles of this section has been to point out ways by which factors that contribute to costs can be considered in arriving at a proposed plan.

To be of any real value, criteria must be capable of being applied to the proposed plans while still on paper and before an installation is made. The criteria must be reasonably accurate and easily applied, and must show some close relationship to the various costs of operation. Thus, the criteria will deal with three types of costs:

1. Direct labor.
2. Direct material.
3. Burden or overhead expenses.

The effects of various proposed plans can be judged by:

1. Direct labor:
   a. Reduction in task time.
   b. Elimination or reduction in manual effort.
   c. Reduction in distances to obtain tools, materials, and instruction.
   d. Reduction in distances and waiting time to satisfy personal needs.
   e. Improvement in working conditions: light, heat, noise, dirt, interruptions.
   f. Improvement in employee morale or "will to work."
2. Direct materials:
   a. Elimination of damage to materials or parts in transit.
   b. Means of controlling scrap and waste.
   c. Use of less expensive materials (resulting from improved processing or better product design).
3. Burden expenses:
   a. Better use of vertical space.
   b. Better use of floor space.
   c. Reduction of idle or down time on equipment.
   d. Elimination of necessity for close supervision, written orders, move orders, etc.

e. Substitution of mechanical for manual handling.
f. Elimination of unnecessary movements of materials.
g. Use of gravity for moving materials.
h. Combining movement with processing (as drying on conveyors).
i. Elimination of temporary storage between operations.
j. Elimination of need for more space and equipment by improvement in productivity and utilization.
k. Improvement in flexibility of output (volume, design, variety of product, etc.).

Direct measures of the effectiveness of a plan have been proposed. Each of these measures is useful, but if used alone may be very misleading. It is advisable to use several of these measures to test each proposed plan and to select that plan which minimizes the largest number of the most significant of these criteria. Some of these direct measures are:

1. The expected direct labor cost per piece or unit.
2. The indirect labor costs per piece or unit (should be based on actual cost items that vary among the alternatives rather than on some overhead allocation plan).
3. The materials-handling cost per ton of shipped product.
4. The ratio of direct labor to indirect labor per piece or unit.
5. The distance traveled by each part, in feet.
6. The number of handlings per piece.
7. $$\frac{\text{Number of handlings} \times \text{weight at each stage}}{\text{Shipping weight}}$$
8. The total direct labor hours per piece or unit.

These measures become most valuable when they can be compared with a suitable standard or optimum value. A multi-plant company will compare these measures for a proposed plant with the corresponding values from efficiently operated existing plants. If trade association journals publish such data from individual companies or from the industry as a whole, the individual concern can compare its values with the published data to find out if they are better or worse than its competitors'. Under such conditions, the direct measures become goals that can be reached or bettered. If they must be used only as comparative values among several alternative plans, they are useful in selecting the best of the alternatives but do not indicate whether or not the optimum plan has been devised.

5.5.8 Layout check list. The following questions will provide a check list by which each layout can be checked in order to avoid the most common errors.

A. Space Utilization and Disposition

1. Is there sufficient space for the operator to perform all his tasks at the machine?
2. Is there sufficient space around the machine for easy maintenance?
3. Is the machine locked in by other machines, so that it cannot be moved without first moving other machines?
4. Is there space for the tools, auxiliary equipment, jigs, fixtures, tables, and tool cabinets for the proper operation of the machine?
5. Is there sufficient space for the worked and unworked parts or the "float"?
6. Is the machine accessible, so that the worker can get to and from his work station without danger of injury?
7. Is the machine located too close to the aisle or conveyor for the safety of the operator or others?
8. Is too much space allowed, so that the operator becomes inefficient?
9. Is vertical space used for storage and materials handling?
10. Are storage areas (tool, raw materials, in-process or finished goods) adequate for expected volumes?
11. Are personnel service areas adequate for the number of employees expected?

B. Machine Location Factors

1. Is the machine located at the best position or angle for the effective supply

and removal of materials, and for effective use of floor space?

2. Is the machine in the best location for both natural and artificial lighting?

3. Does the location of the machine subject the operator to excessive heat, noise, drafts, or fumes from other machines or processes?

4. Is the location safe from flying particles, explosions, fire, moving trucks and cranes, and other hazards?

5. Is the machine located properly in relation to the sequence of operations?

C. Services and Distribution of Services

1. Is the distribution system for steam, gas, air, and power designed for ease of re-layout and installation of equipment?

2. Has excess capacity been provided in the distribution system so that additional equipment can be installed?

3. Will re-layout or expansion necessitate relocation of main or trunk lines?

4. Are all pipe lines and conduit clearly labeled?

5. Are tap-offs, control panels, and valves provided at convenient intervals so that interruptions will be minimized?

6. Are service lines exposed for ease of maintenance?

7. Are service lines protected from freezing, damage by materials-handling equipment, and machine operation?

8. Are protective devices, hoods, baffles, insulators, and the like provided to protect personnel and equipment?

9. Has too much space been allocated to aisles?

10. Are there too many aisles or are aisles too wide?

11. Are aisles clearly marked and do they have too many turns or obstructions?

12. Are aisles wide enough to provide for the volume of traffic expected and the manipulation of the expected loads?

D. Storage Areas

1. Are tool cribs and storage areas at convenient locations?

2. Are storage areas frequented by the employees at excessive distances from their work areas?

3. Do the storage areas provide protection from theft or loss of materials of high value?

4. Are special storage facilities provided for paints, oils, acids, gas cylinders, chemicals, flammable and explosive substances?

5. Does the location of storage areas complicate the receiving and checking of incoming materials?

6. Does the location of storage areas increase the length of hauls of large volumes of materials?

7. Does the arrangement of storage areas permit the use of mechanical handling facilities?

8. Are there provisions for the inspection of incoming materials?

9. Are storage facilities, shelves, racks, bins, trays, etc., selected for ease of filling and issuing?

10. Are storage facilities centralized or decentralized according to the particular needs of the area served?

11. Are storage areas planned and equipped for systematic identification and location of items in the area?

12. Is proper use made of vertical space in storage areas by means of mezzanine floors, palletized loads, etc.?

13. Is enough space allocated to storage to care for peak loads?

14. Are in-process storage areas located for maximum efficiency of the materials-handling system?

E. Personnel Facilities

1. Are employee entrances at too great distances from work stations?

2. Are washrooms, lockers, and toilets located at frequent intervals (preferably within 200 feet of work stations)?

3. Has a sufficient number of toilets, lockers, and wash basins been provided on each floor and near each department?

4. Have water fountains been provided at frequent intervals (100 to 150 feet apart)?

5. Are first-aid rooms or dispensaries located conveniently to the work areas, and readily accessible?

6. Are employee services (counseling, saving and loan, legal, income tax, commissary, insurance programs) located conveniently to the employees' entrance?

7. Are working conditions (temperature, humidity, noise, light, cleanliness, and working position) planned to be as pleasant as the tasks will permit?

8. Is food service clean, economical, of good quality, adequate, and available conveniently to all employees?

9. Are all personnel facilities properly ventilated, maintained in extremely clean condition, and planned for ease of maintenance?

10. Are medical service, first-aid stations, and dispensaries adequate for the number of employees and the hazards present in the plant?

6. OFFICE LAYOUT

Office layout involves two problems: the location of the offices and the arrangement of the furniture and equipment within the offices.

6.1 OFFICE LOCATION

The object of office planning is to provide for the smoothest and most direct flow of communications, paperwork, and information from department to department in the necessary sequence so that each department can perform its function as efficiently as possible. The functions performed by the several departments can be compared to the operations performed in the manufacture of a product, and the location of offices can be thought of as a special case of department location. Some offices will embody the principles of process or functional layout, in that a number of persons in each office or department perform similar work—i.e., accounts-receivable clerks in an accounting office. Other offices will embody the principles of line layout, in that a paper form will pass through the hands of a number of persons, each of whom performs some specialized function on it.

The location of the offices can be determined by analyzing the functions relative to:

The organization chart.
Communications.
Paperwork flow.

6.1.1 The organization chart. The organization chart of a company usually shows the lines of authority and the lines of response between and among the auxiliary and producing departments. The chart should show very clearly how the information flows from one division to another, the level of responsibility, where the information originates, and its ultimate destination. The organization chart will usually provide a guide for groupings of offices and will indicate what other offices or departments should be located near by. The use of an organization chart, however, is seldom a practicable solution in that the building is not constructed like an organization chart and the chart does not necessarily indicate the amount of space that will be required by the different departments. The nature of the activity may be such that a location determined by this method would have serious disadvantages. For instance, the drafting department is tied closely to the factory, but it should be located in a clean, quiet area and out of the principal traffic patterns to reduce interruptions and disturbances.

6.1.2 Communications. The most important aspect of office location is that of communication with other departments, customers, vendors, and carriers. Since written and oral (telephone) communication is not seriously limited by distance, those offices whose principal flow of work is conducted by these means need not be located adjacent to or even near closely related departments. It is only when the communication must be conducted person-to-person that the location of offices becomes important. Thus, the plant manager, production planning and control, methods engineering, motion and time study, plant maintenance, and other activities that must perform part of their work in the factory area should be located conveniently to the factory. Offices that have

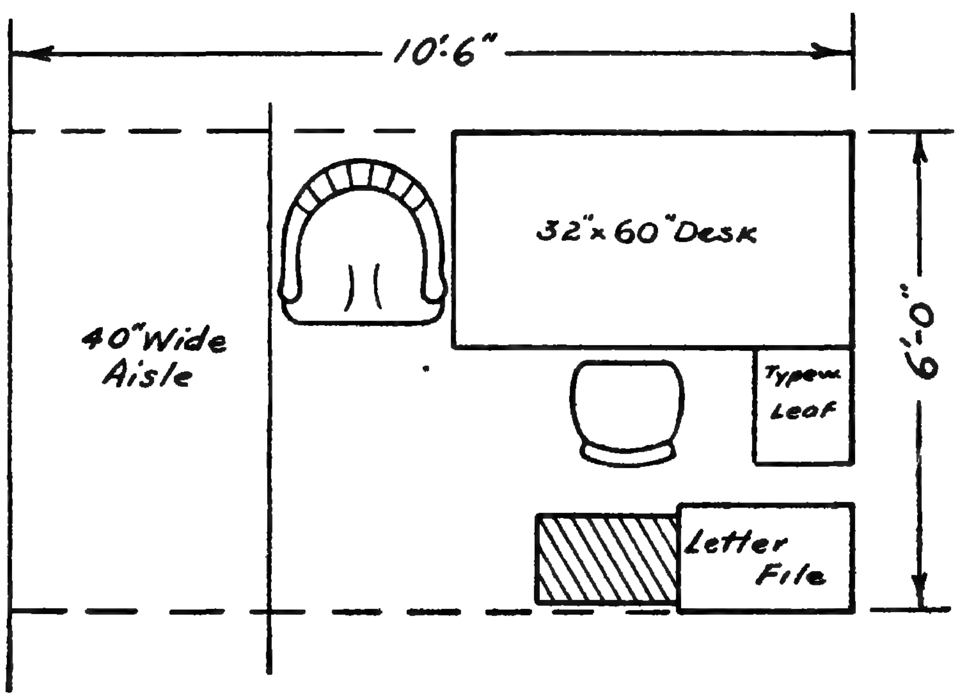
to receive persons from outside the plant (salesmen, customers, advertising agencies, common carriers) should be located conveniently to the street or plant entrance so that visitors will not have to go into the factory area. These offices may be located in the business district of the city, a number of miles from the factory site. Offices that deal primarily with management functions should be close to those persons served.

Consideration of the communication problems helps to establish the general location of offices and auxiliary departments. Specific conditions, such as size and nature of space available at the different locations, orientation relative to light and prevailing winds, and the character of the work performed, will help to determine the specific location of the several departments.

6.1.3 Flow of paperwork. Just as the process flow chart is the basic instrument in determining the location of machines, the process flow chart of paperwork can be used as a basis for arranging the office functions. The sequence of operations on forms for any purpose can be shown by the chart, and the same sequence can be used for the location of offices or desks (for the particular functions) within an office. The process flow chart is particularly useful in arranging offices for banks, mail-order houses, insurance companies, and central offices for manufacturing concerns. The procedures and systems commonly used to accomplish the clerical work in sales, purchasing, production control, inspection, and accounting usually employ the principles of division of labor and specialization of labor. Thus, one form usually passes through a number of hands before all the information is recorded or noted. These operations can be lined up in sequence within the office in many cases. (See Section 6 for examples of such charts.)

6.1.4 Personal considerations. It is not uncommon for the location of offices to be determined almost completely by personal preferences. A certain amount of prestige is involved in the location and assignment of space, and company policy may dictate that key individuals be given their choice of offices before general assignments are made. The wise planning engineer will make a thorough study of office needs and the most desir-

FIG. 8.22 A TYPICAL PRODUCTION CENTER LAYOUT FOR STENOGRAPHIC POOL.



From Ireson, *Factory Planning and Plant Layout*, p. 145.

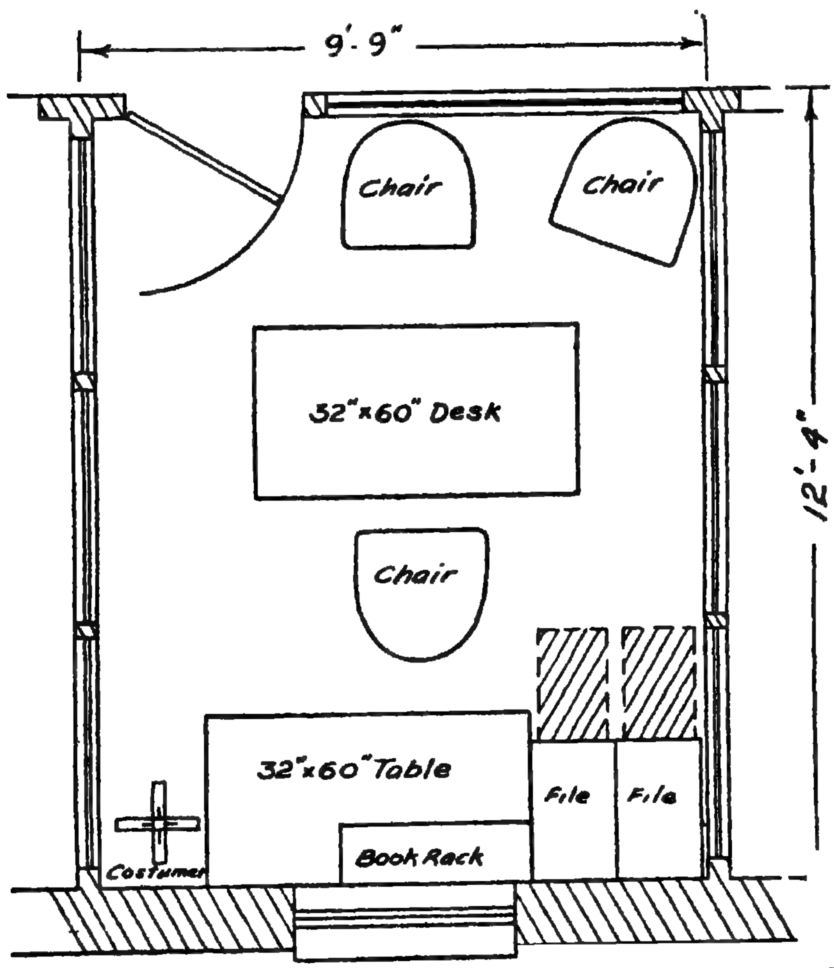
able locations from the standpoint of functions performed and then proceed diplomatically to solicit opinions and preferences. He should be prepared to point out difficulties that will arise if the personal preferences will result in serious errors.

6.2 SPACE ESTIMATION

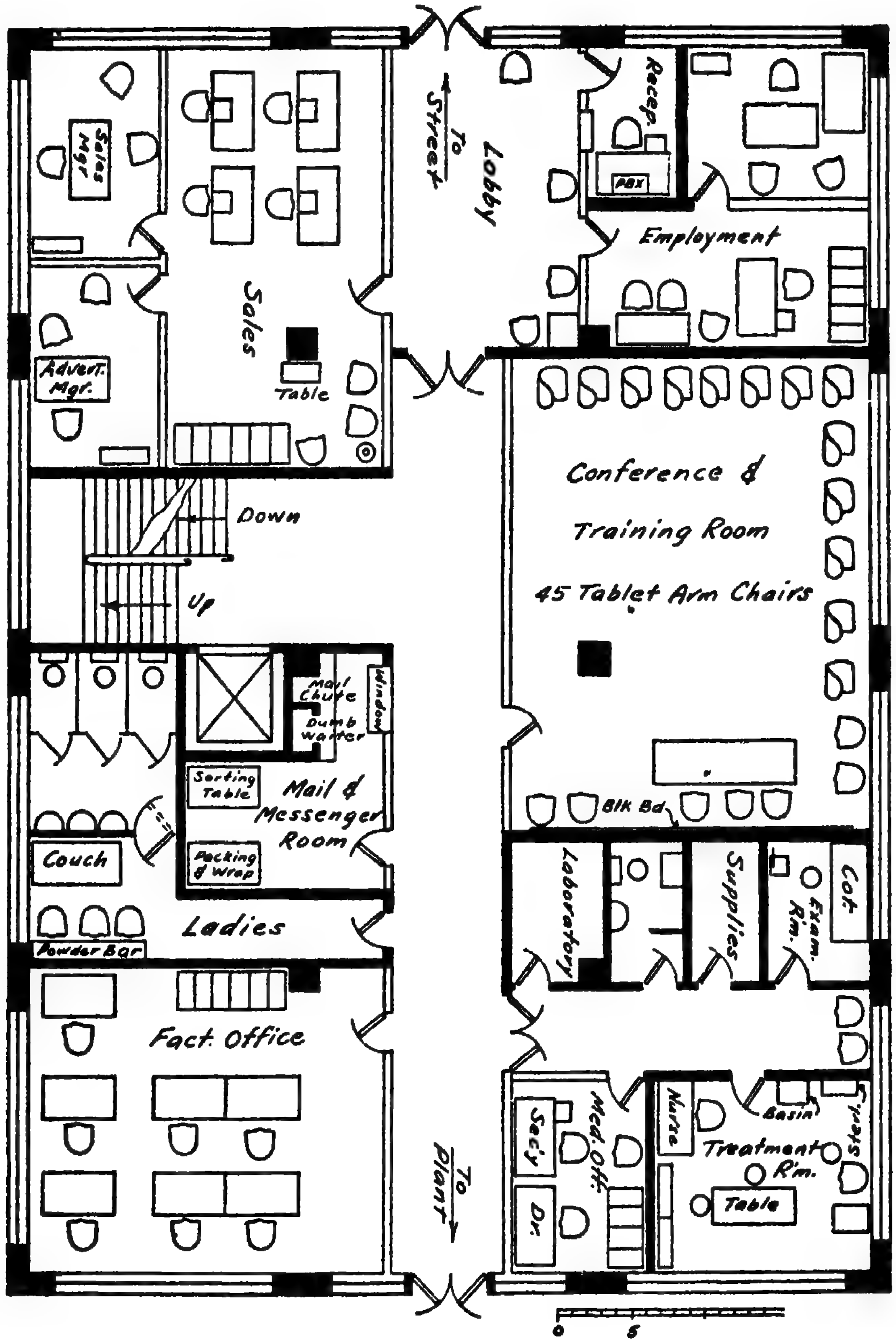
The space requirements for offices usually bear some direct relationship to the number of employees to be accommodated. Some general rules have been devised for estimating space needs purely on the basis of the number of employees, but a more accurate estimate can be reached by making separate estimates of space for desks, filing, aisles, and private offices. Different functions within the same company require radically different ratios of desks, chairs, file cabinets, and other office equipment. It is advisable to prepare a typical production-center layout for each different function to be performed and to multiply the space for each production center by the number of persons to be employed in that function (see Art. 5.4.3). Figure 8.22 shows a production center for a function that requires an extra chair and a file cabinet, and with 40-inch-wide aisles between all desks. This function requires about 65 square feet.

Figure 8.23 shows a typical private office for a junior executive. Its space, including half of a six-foot-wide aisle, is approximately 150 square feet.

FIG. 8.23 TYPICAL PRIVATE OFFICE DESIGNED FOR SPACE ECONOMY WITH EFFECTIVE ARRANGEMENT.

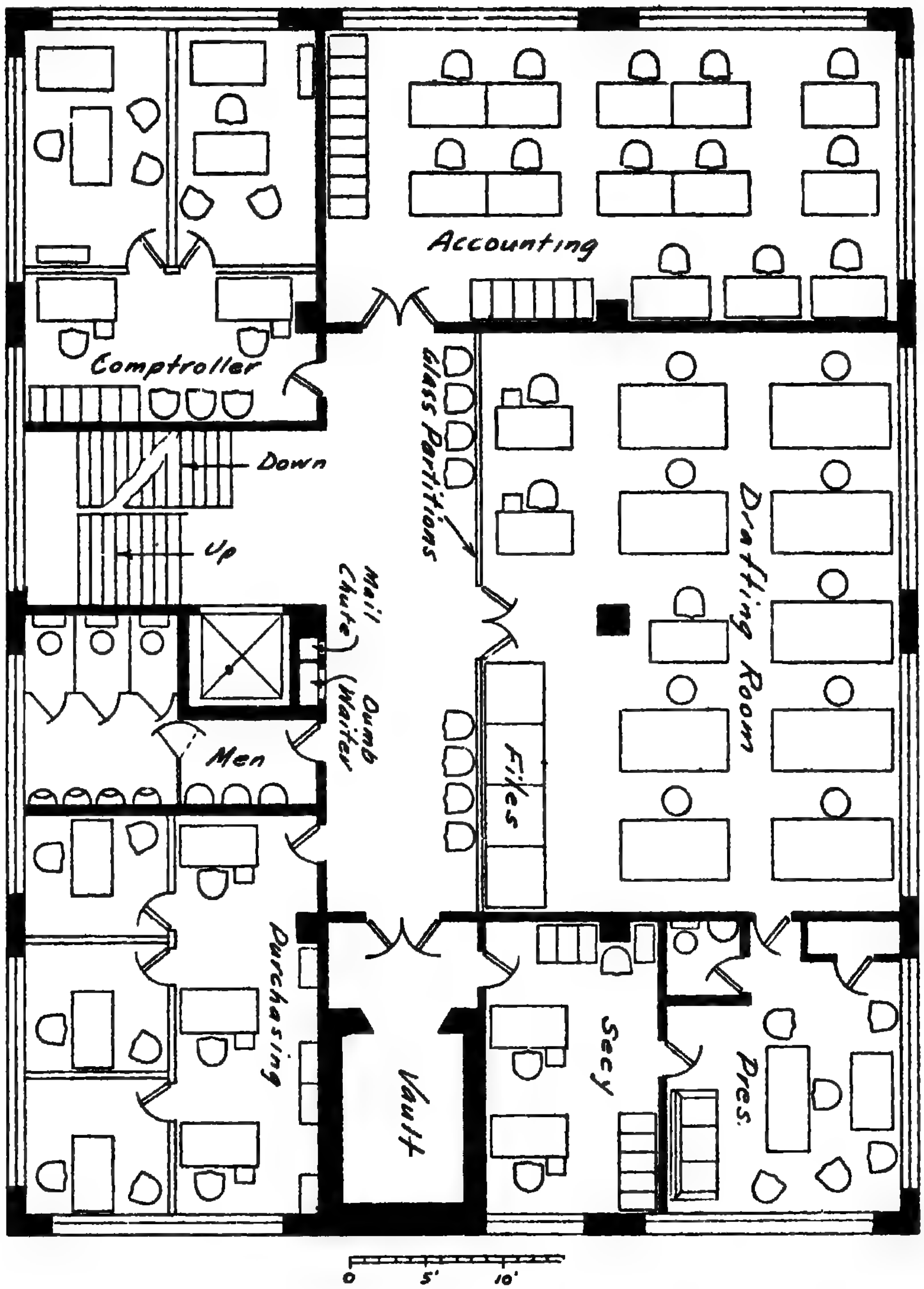


From Ireson, *Factory Planning and Plant Layout*, p. 140.



From Ireson, *Factory Planning and Plant Layout*, p. 265.

FIG. 8.24 FIRST FLOOR PLAN FOR MANUFACTURING COMPANY'S OFFICE BUILDING.



From Ireson, *Factory Planning and Plant Layout*, p. 153.

FIG. 8.25 SECOND FLOOR PLAN FOR MANUFACTURING COMPANY'S OFFICE BUILDING.

The production-center area may be as low as 42 square feet, for a single desk and chair and half of a four-foot-wide aisle, to around 100 square feet if wider aisles are used and if extra file cabinets are necessary.

Space for private offices may run from less than 100 square feet for functional offices (see Figs. 8.24 and 8.25) to over 500 square feet for major executives. The trend is away from exceptionally large private offices to more modest offices and the provision of one or more conference rooms to be used for meetings involving five or more persons.

An example of the space estimate for a certain department follows:

Private offices 2 10′ x 12′	240 sq ft
General office	
10 desks (desk, 2 chairs) 6′ x 8′	480 " "
Filing section	
1 vault 10′ x 16′	160 " "
25 file cabinets, 6 sq ft each	150 " "
Lockers 16 4 sq ft each	64 " "
Aisles (not accounted for in previous estimates)	
Main 5′ x 30′	150 " "
Cross 3′ x 40′	120 " "
Total	1,364 sq ft
Use area approximately 35′ x 40′ or 30′ x 50′	

6.3 OFFICE LAYOUT

There are a few principles to guide the arrangement of the furniture and equipment in offices. Consideration of these principles will help to assure that offices will be efficient and comfortable. These principles are:

1. Provide sufficient aisles to prevent work interruption by persons entering and leaving the area. Provide aisle access for each desk.
2. Divide offices and functions so that distracting traffic will be minimized in each office.
3. Arrange desks and work tables so that both natural and artificial light fall on the desk from the same general angle.
4. Have the worker's back or side to the windows, never have worker facing windows.
5. Arrange desks back to front (all in the same direction) unless the functions require constant collaboration of more than two persons.
6. Locate functions that require frequent visitors nearest the entrance of each office. (In most cases, this will be the chief person in each office group.)
7. Locate filing areas in the less desirable space, but convenient to those using them most frequently.
8. Do not locate file cabinets along heavily traveled aisles.
9. Locate functions requiring greatest concentration away from main aisles, entrances, conference areas, and other distracting influences.
10. Try to avoid placing the front of a desk against a wall.

Figures 8.24 and 8.25 show the first and second floors of a typical factory office building. Some desirable features and some undesirable features are illustrated in these figures. For example, since purchasing has more visitors than the sales department, their locations should be exchanged. The vault is located in desirable office space and could be relocated in less desirable space. File cabinets are located along principal aisles in the accounting department. On the other hand, functions that require most frequent visitors from the factory area or from outside are located on the first floor. Desks and drafting tables are properly oriented with the windows. The central corridor and centrally located stairs, elevator, and washrooms help to control the traffic on each floor. Washroom facilities are on alternate floors for men and women, and are adequate for the number of employees on the two floors. The floor space per person on the two floors is approximately 165 square feet, but these two floors contain a large number of private offices, a large conference room, and a drafting room, all of which increase the per capita amount. The floor space is used efficiently.

7. MATERIALS HANDLING

7.1 IMPORTANCE OF MATERIALS HANDLING

Materials handling is an inevitable part of every manufacturing plant. The magnitude of the problem is indicated by the fact that the cost of materials handling in all forms accounts for from 20 to 50 per cent of the total cost of converting the raw materials into the finished product. It is not uncommon for each part to be handled as many as 50 to 60 times before it is in final form and shipped. These facts alone are sufficient to prove that the materials-handling system should be given exhaustive study whenever a new factory is being planned or an existing one is being remodeled.

The cost of materials handling arises from two sources: (1) the cost of owning and maintaining equipment and (2) the cost of operating the system. In general, higher investments in mechanical, semi-automatic, or automatic handling equipment are justified by the reduction of operating costs resulting from the better equipment. If the reduction in operating costs is greater than the increase in other costs, a net saving has been obtained. This is the usual attack on the problems of high handling costs in existing plants, but another attack, often overlooked, is available. That attack analyzes the selection and arrangement of the production facilities and attempts to eliminate the need for separate handling facilities.

The first objective, then, should be to select the most suitable production equipment and so arrange it within the factory buildings that the need for materials handling will be eliminated as far as practicable. The second objective should be to select the materials-handling system that will accomplish the required handling at the lowest over-all cost. It is obvious that successful factory planning requires the simultaneous consideration of materials-handling problems, the selection of production equipment, and the arrangement of physical facilities. These factors are inseparable.

7.2 TERMINOLOGY OF MATERIALS HANDLING

Certain terms will be used in the following sections that have special meanings with regard to materials handling. Some of these terms are commonly used in the industrial vocabulary, whereas others are subject to controversy.

Materials handling: Any movement of materials, vertically, horizontally, or both, manually or mechanically, in batches or one piece at a time.

Transport: * The movement of a lot or batch of product from one production center or storage area to another production center or storage area. The purpose of transport is to locate the product for additional operations or storage. Transport is usually accomplished by "move men" and/or materials-handling equipment.

Transfer: The movement of pieces, singly or in small quantities, from a container to a machine where the operation is performed and back into another container. This handling is usually performed by the machine operator, and is not formally charged against the cost of materials handling.

Almost all materials are handled in either bulk or packaged form. This classification is useful in selecting a suitable handling system for the particular material.

Bulk materials: Any materials that are loose and handled in quantities without being contained in bags, boxes, barrels, and the like. Materials-handling equipment for bulk materials supplies the temporary container, and the movement takes place by means of features such as pipes, buckets, belts, chutes, and tubes. The material is usually deposited in a bin, tank, elevator, or other container, from which it is fed into the processing equipment.

Packaged materials: Materials con-

* It is believed that Preben Jessen, a consulting engineer in materials handling, originated the use of the terms *transport* and *transfer*, with the limitation of a movement of five feet on transfer.

tained in convenient-sized packages, such as bags, boxes, crates, cartons, cans, barrels, or other types of containers that can be handled as individual pieces by the materials-handling system.

4. *Unit load:* A certain number of packaged units mounted together on a skid, pallet, platform, or skid-box for movement as a single unit. The unit load may be made up of a certain number of individual pieces secured to a pallet or deposited in a box. It is most frequently used in connection with fork lift trucks and for purposes of warehousing, rail, and ship movement, but may be used with bulky items in manufacturing operations

5. *Rehandle:* A term applied to the movement of a piece, package, or unit load. Rehandle consists of the pick-up, move, and set-down. The term is most frequently used in analyzing handling operations to discover unnecessary or excessive handlings that can be eliminated.

7.3 PRINCIPLES OF MATERIALS HANDLING

Principles of materials handling—qualitative statements that are generally true—can be used to guide the analysis of and the decision regarding a handling problem. The purpose of the principles is to prevent serious mistakes resulting from oversights or incomplete examination of a problem. The principles do not give the solution; rather, they point out important considerations in the solution. In fact, some of the principles tend to be contradictory, but even these perform the useful function of emphasizing that the conditions unique to one problem must be analyzed from two or more entirely different viewpoints.

The following principles have been adapted from those contained in Stocker's *Materials Handling** and from the author's own experience.

1. The objective of materials-handling analysis should be the elimination of the necessity for handling as a separate function.

2. Methods studies should be used to determine the best equipment and handling methods for the particular conditions encountered (see Section 5).

3. Engineering economy principles should be employed to select the most economical alternative method or equipment when methods studies are not conclusive (see Section 3).

4. The prospective economy in materials handling will not be obtained unless the handling functions are coordinated with the other activities of the plant by efficient control systems (see Section 6).

5. Operating economy is obtained by:

a. Reducing idle or terminal time of handling equipment to the minimum.

b. Increasing the size of the unit handled or the unit load.

c. Employing powered, mechanical equipment to perform the moving task.

d. Replacing obsolete equipment and methods with the most economical substitutes.

e. Employing versatile equipment that can be used for several handling jobs.

f. Selecting equipment of standard design instead of specially designed and built equipment.

g. Reducing the ratio of the dead weight of the equipment to the live weight of the load to a minimum.

h. Increasing the speed of the handling function without corresponding increases in other operating costs.

i. Providing inspection and preventive maintenance to reduce failures and emergency repairs.

j. Maintaining safe working conditions and training materials handlers in safe practices.

k. Substituting mechanical controls, timers, and actuators for human operators.

6. The economy of materials-handling systems is measured by the cost of handling per ton or unit for a specific movement.

7. Materials-handling costs increase with an increase in distance handled, but

* Harry E. Stocker, *Materials Handling*, 2nd ed. (New York: Prentice-Hall, Inc., 1951).

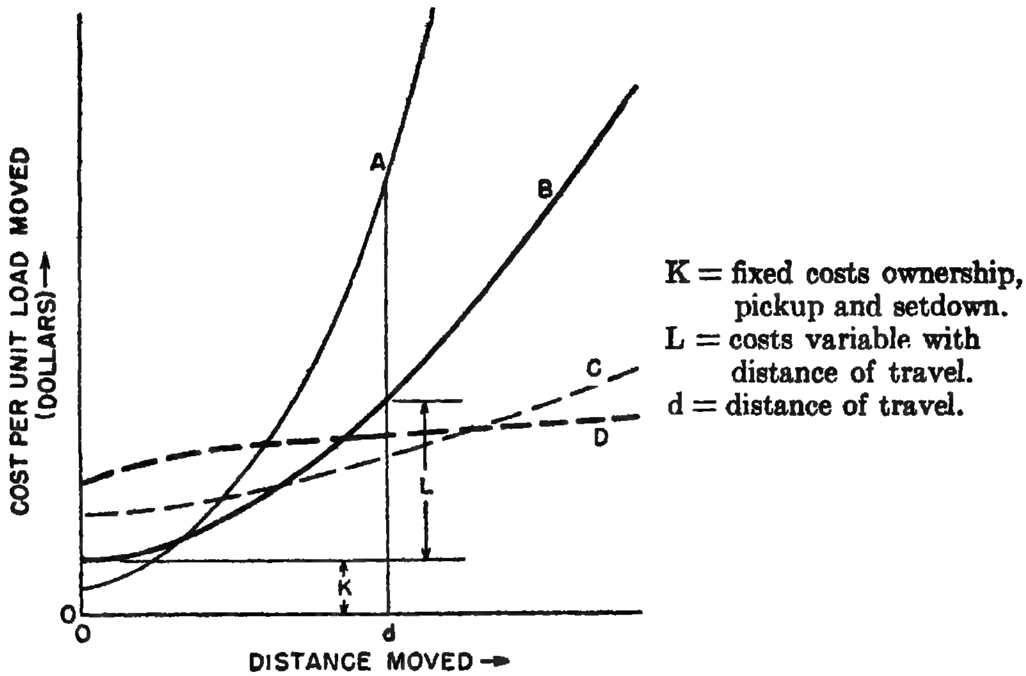


FIG. **8.26** TYPES OF COSTS CURVES FOR VARIOUS MATERIALS-HANDLING DEVICES VERSUS THE DISTANCE FOR A PREDETERMINED UNIT LOAD.

the rate of increase differs with the systems and is not necessarily uniform relative to distance (see Fig. 8.26).

8. Materials should be moved by gravity whenever the economies thus obtained are not counteracted by extra costs of factory facilities or operating labor.

9. The system selected should provide for flexibility to accommodate changes in output, products, or layout.

10. Whenever materials-handling methods affect production or factory costs, the combination that minimizes the total of such costs should be selected.

11. Whenever possible, the handling system should be combined with the production equipment so that transport and transfer are accomplished without human assistance and without process interruption.

7.4 ANALYSIS OF MATERIALS-HANDLING PROBLEM

The solution of any materials-handling problem requires the accumulation of a large amount of factual data and their analysis relative to the particular plant and production conditions. This analysis can best be performed when the collection and analysis of the data follow a logical pattern. Such a pattern will include the following items.

1. Plant factors.
2. Methods factors.
3. Products and materials.
4. Present handling methods and equipment.
5. Proposed handling methods and equipment.
6. Cost data and economic analysis.

7.4.1 Plant factors. Plant factors refer to all the conditions of the building and the layout as they now exist or as they are proposed to be. The analyst needs to have data on the size and relative location of buildings and interior features such as column spacing, location of doors, elevators, stairs, and columns, floor load capacity, ceiling heights, aisles, piping and power circuits. These conditions establish the plant restrictions within which the materials-handling system must function. They in turn become re-

strictions upon the types of handling systems and equipment that can be operated within the plant. It is important for the analyst to know which conditions must remain as they are and which can be altered to accommodate a more economical system.

7.4.2 Methods factors. Methods factors encompass all the details of production methods, equipment, processes, sequence of operations, production plan (whether interruptible or continuous), temporary storages, volumes to be handled, and so forth. These methods factors describe the materials-handling problems against a background of space, machines, weights and volumes of materials, and operators, so that the engineer can establish the specifications for a satisfactory materials-handling system. (Art. 7.5 deals with the specifications for a system in terms of the features required.) The methods employed in production impose special restrictions on the handling system. These restrictions can be used to eliminate whole groups of handling systems, thereby simplifying the selection or indicating the methods that offer an opportunity for improvement or economy.

7.4.3 Products and materials. The specific kinds of products and materials to be moved, and the volumes and distances of each move, provide the engineer with additional specifications for the system. The nature of the products, whether packaged or in bulk, fragile or rugged, dense and heavy or light and bulky, establishes the operating conditions to be met, and the quantities per period of time establish the load capacity and speed required of the system. Hazards or hazardous conditions are recognized, and protective equipment or measures are incorporated in the specifications.

Not only the existing products and materials, but also the possible changes in them in the future, must be considered if the materials-handling system is to have the prospect of being economical over a reasonable period of time. Flexibility of the system is a guard against early obsolescence.

7.4.4 Present handling methods and equipment. If the present materials-handling problem is in an existing plant, it can be assumed that there is existing handling equipment and that it is either inadequate, expensive to operate, or unsuited to the handling job. Before existing equipment is scrapped and new equipment purchased, it is essential to realize that the problem may have come about as a result of poor utilization of the present equipment, or a plant layout that prevents its proper utilization, or both. Thus, the investigation of a materials-handling problem should include a careful analysis of the effectiveness of the existing system. Points of failure, effectiveness of the coordination of handling with production, effects of layout on the utilization of the equipment and the coordination, and the results (in terms of cost) should be determined. With this information, the engineer may be able to point out ways by which the existing system can be used effectively through such actions as relocation or re-layout of certain departments or machines, the purchase of auxiliary equipment, the purchase of a few additional pieces of the same type, or the concentration of the existing equipment on jobs for which it is suited and the purchase of other types of equipment for the other handling tasks.

7.4.5 Proposed handling methods and equipment. The fact that existing equipment can be used, apparently with satisfactory results, does not mean that this plan is necessarily the most economical. Only when the engineer has obtained all the data listed in the four preceding articles is he in a position to investigate the available materials-handling systems to find those that will satisfy the needs of the plant. It is axiomatic that the most economical solution cannot be selected unless *all* systems that will satisfy the requirements have been identified as alternatives. Thus, having formulated the problem and established the specifications for the handling system, the engineer will proceed to use every possible source of information in order to obtain a complete catalog of functionally satisfactory systems, their first costs,

operating characteristics, operating costs, prospective lives, and so on. He will then analyze the several systems and by preliminary economic analysis will discard all but the two or three most economical systems.

7.4.6 Cost data and economic analysis. With the number of alternatives reduced to three or four systems, including the use of existing equipment as formulated in Art. 7.4.4, the analyst is ready to make exhaustive studies of the several systems. Complete cost information will be obtained from plants using similar equipment. Repair and maintenance histories will be accumulated. Firm bids on first cost and installation will be obtained. Irreducible advantages and disadvantages of each alternative will be enumerated. Finally, a complete engineering economy study will be made that will include all the pertinent information regarding the systems; and also the effects of taxes, insurance, and depreciation or amortization. The resulting amounts are comparable and, the irreducibles being equal, the system that gives the lowest prospective cost will be selected. Since this final selection is usually not made by the engineer but by the management, it is very important that the study be complete in every respect and present the proposals in clear, understandable language.

7.5 FEATURES OF MATERIALS-HANDLING SYSTEMS

The selection of a materials-handling system involves two types of problems: (1) technical problems and (2) economic problems. Article 7.4 treated these two problems in general terms. The technical problems are involved in determining which handling systems will satisfactorily perform the required handling function. The solution of the technical problems provides the several alternatives that are then analyzed as economic problems. This article deals with the features of the handling system that are considered within the technical problems. The specifications for a technically satisfactory system can be almost completely prescribed in terms of the following features.

7.5.1 Flexibility. Flexibility of a materials-handling system refers to its adaptability to changes in operating conditions. These changing conditions involve different products of varying size, nature, shape and weight, changes in volumes to be handled, new layouts, machinery, and production processes. Seasonal and cyclical changes in business, development of new or complementary products, obsolescence of products, shifts in markets, and obsolescence of production equipment are some of the common causes of changes in the handling problem. The greater the probability that these changes will occur, the greater is the need for a *flexible* materials-handling system.

Flexibility of handling systems may be illustrated by such characteristics as:

1. Ability to handle efficiently different sizes of packages simultaneously and at irregular intervals. (Rubber belt conveyors, roller conveyors, fork lift trucks, tractor-trailer trains, spiral chutes.)

2. Ability to be rearranged with ease to accommodate a different path of movement. (Fork lift trucks, roller conveyors on portable stands, and sections of powered conveyors, as opposed to overhead monorails, under-floor drag lines, or elevators.)

3. Ability of standard equipment to be fitted with special jigs or fixture to do a specialized job that would otherwise require a specially designed system. (Monorail systems for finishing rooms with different types of hangers to accommodate widely varying sizes and shapes or products through a sequence of operations.)

7.5.2 Space requirements. All materials-handling systems require space. Some require floor space constantly, whereas others use it intermittently. Some occupy vertical space that is otherwise unused. Trucks, trailers, and mobile equipment use aisle space that is also used for personnel traffic, but may require that the aisles be larger than would otherwise be necessary. The selection of a system that makes the most economical

use of the available space, both floor and vertical, may eliminate the need for building expansion. The storage facilities are usually integrated with the handling system, and the use of pallets, stacking bins, or mezzanine floors may double or triple the storage capacity, provided the handling system is properly selected. Through such related economies in the utilization of space, the materials-handling system can effectively expand the plant capacity without long-term commitment of capital funds in plant buildings.

7.5.3 Supervision. All materials-handling systems require some direction, coordination, and supervision to accomplish effectively the assigned task. However, as the systems progress downward from the completely automatic, continuous ones to the system of individually dispatched mobile units, the amount of human effort required for supervision increases rapidly. Since the cost of human effort for supervision, coordination, and operation is a continuing annual expense, it is profitable to use the most automatic system practicable for the existing conditions. Conditions that tend to indicate automatic or semi-automatic systems are:

1. A stabilized line of products.
2. Fairly uniform volumes or loads.
3. Standardized tasks or fixed patterns of movement.
4. A sufficient volume to justify the investment even if the several parts of the system are used only intermittently.

In any semi-automatic or automatic systems, the probability of breakdowns and the consequences in lost production, cost of maintenance, and idle labor should be considered in making the final decision.

7.5.4 Speed. The rate of movement of the conveying equipment plays a substantial part in the determination of the most economical system. There are two points to be considered: (1) Should speed be fixed or variable? (2) Will the speed, in connection with the load capacity, provide the required volume of movement? Whenever the system is to be an integral part of the production system, as in mechanically paced work, it is almost essential that the speed be variable. Poor quality of materials, "green" workers, absenteeism, and variations in the production process are other reasons for selecting a variable-speed mechanism.

An increase in the speed of operation may permit the selection of a lower-capacity unit, with lower investment. However, the consequences of high speed, such as greater damage to materials, generation of heat, higher maintenance, and the hazards of a sudden breakdown, should be carefully weighed against the advantages.

7.5.5 Power. The nature and location of the movement may limit the handling equipment to the use of certain kinds of power. Mobile units with unlimited range must have self-contained power units, internal combustion engines, or batteries. Fixed systems, with limited areas of service, may use gravity, electricity (line), hydraulic power, or internal combustion engines. Both the initial investment and the cost of the power or fuel vary with the type of power used. Restrictions on the use of certain power sources (*i.e.*, the use of gasoline engines in enclosed space or areas containing explosive materials) may eliminate the possible use of the most economical or most satisfactory system.

7.5.6 Path of movement. The path of movement can be classed as either fixed or variable, and, if variable, as limited or unlimited. Certain materials or parts follow the exact path through a plant and go through the same sequence of operations. The path of movement is fixed, and handling systems that provide fixed paths of movement, such as the roller conveyor or overhead chain-driven monorail, can be used for continuous or intermittent movement of materials over this path.

If the volumes are limited, and if the same handling units must serve many different materials or parts, the path of movement must be variable. The path is limited variable if the movement is to be confined to some relatively small

area. Examples of the limited-variable path include the use of drag lines to handle bulk materials (as from a coal storage bin into a power plant), a bridge crane that provides completely variable movement within the limits of its runway, sectional conveyors that can be readily shifted about within a warehouse, and conveyor systems that incorporate a good switching system to permit a large number of different movements. Unlimited-variable paths require the use of mobile units, such as fork lift trucks, tractor-trailer trains, hand trucks, and mobile cranes.

Variable-path equipment generally requires greater supervision and coordination, in order to effect the desired movements on schedule, than does the fixed-path or even the limited-variable-path equipment. On the other hand, it is almost axiomatic that fixed-path equipment can only be used in connection with line or product layout.

At the same time that the path of movement is considered, it is important to analyze the possibilities of performing both the transport and transfer functions with the handling equipment. It is impossible to enumerate all the possible methods of accomplishing this objective. Some are very simple and others are elaborate and very costly. The nature of the product, the nature of the operation or process, the volumes to be handled, and relative time standards for successive operations are factors that enter into the analysis and the design of such a system.

Temporary storage of materials on the handling system is one way of eliminating rehandlings. This possibility should be studied along with the determination of the path of movement.

7.5.7 Load capacity. The term *load capacity* refers to the ability of the equipment to carry a certain load. Unfortunately, however, all equipment is not rated on the same basis. Most conveyors are rated upon the safe load in pounds per foot of length. Fork lift trucks, trailers, and shop trucks are rated by the weight that they will carry. In the case of the fork lift trucks, this weight is specified at a certain distance from the face of the forks, but actually is determined by the distance from the center of the front wheels to the center of gravity of the load. Different types of fork trucks with the same rated capacity may have very dissimilar actual load capacities.

In the case of troughed belt conveyors or screw conveyors, the nature of the bulk material, size of particles, density, and angle of repose determine how much of the material can be moved under various conditions and by different sizes of conveyors.

It is the combination of the load capacity and the speed of the equipment that really defines the output capacity of the handling system.

7.6 SELECTING THE HANDLING SYSTEM

There are literally hundreds of available materials-handling systems of standard design from which to choose two or more technically satisfactory systems for complete economic analysis. Since it would be economically impracticable to make a complete study of every possible system, it is essential to eliminate a large number of systems quickly and easily without running any serious risk of eliminating one of the more economical ones. It is for this reason that Arts. 7.4 and 7.5 have emphasized, first, the collection of the necessary information to enable the engineer to completely understand the handling problems, and, second, the specification of the features that will make up a technically satisfactory handling system. By following these ideas and by using a check list such as that shown in Fig. 8.27, the engineer is able to locate quickly the types of handling equipment that satisfy the requirements. It will be noted that the features described in Art. 7.5 are repeated in the headings of Fig. 8.27, and that check marks identify the properties of each of the more common handling devices.

Since each type of equipment is manu-

MATERIALS HANDLING EQUIPMENT SELECTION CHART

	Materials		Movement			Supervision Required			Path			Speed			Power				Load			Space		
	Bulk	Packaged	Vertical	Horizontal	Combination of Vert. & Horiz.	Close Supervision & Detailed Dispatch	Little Supervision & Detailed Dispatch	Automatic or Semi-Automatic	Completely Variable	Fixed Path	Fixed Area	Variable	Fixed	Either Fixed or Variable	Electricity - Line	Electricity - Bat	Internal Combustion	Gravity	Unit Load with Limits	Continuous Loading Max. Load per Unit	Fixed Units by Spacing of Carriers	Minimum Width Aisles	Constant Utilization of Fixed Area	No Floor Space
Trucks Industrial																								
Manual																								
4 wheeled platform	X	X		X		X			X			X			manual power				X			X		
2 wheeled platform	X	X		X		X			X			X			manual power				X			X		
2 wheeled special (barrel, etc.)		X		X		X			X			X	•		manual power				X			X		
Dollies		X		X		X			X			X			manual power				X			X		
Pallet Lift		X		X		X			X			X			manual power				X			X		
Powered																								
Driver-walk																								
Pallet Lift		X		X		X			X			X				X	X		X			X		
Platform		X		X		X			X			X				X	X		X			X		
High Lift Fork	X[1]	X		X	X	X			X			X				X	X		X			X		
Driver-ride																								
Pallet Lift		X		X		X			X			X				X	X		X			X		
Platform		X		X		X			X			X				X	X		X			X		
Low Lift Platform	X[1]	X		X		X			X			X				X	X		X			X		
High Lift Platform	X[1]	X		X	X	X			X			X				X	X		X			X		
Telescoping Fork Lift	X[1]	X		X	X	X			X			X				X	X		X			X		
Tractors and Trailers																								
Industrial Tractor																								
3 wheeled																								
4 wheeled																								
Industrial Trailer																								
According to wheel arrangement	X[1]	X		X		X			X			X				X	X				X	X		
Cranes, Hoists, and Monorails																								
Crane																								
Overhead bridge travelling	X[1]	X			X	X					X			X	X				X					X
Gantry	X[1]	X			X	X					X			X	X				X					X
Jib		X			X	X					X			X	X				X					X
Hoists																								
Chain manual	X[1]	X	X			X					X	X			manual power				X					X
Elec motor drive	X	X	X			X					X	X			X				X					X
Pneumatic	X	X	X			X					X	X			X				X					X
Monorail																								
Carrier	X[1]	X		X	X		X			X					X				X				X	
Trolley		X		X	X		X			X					X						X		X	
Chain Trolley		X		X	X		X			X					X						X		X	
Conveyors																								
Roller Gravity																								
Spiral		X	X		X			X		X		X						X		X			X	
Portable		X		X	X			X		X		X						X		X			X	
Fixed		X		X	X			X		X		X						X		X			X	
Roller Live																								
Chain Drive		X		X	X			X		X				X	X					X			X	
Belt Drive		X		X	X			X		X				X	X					X			X	
Wheel, Gravity																								
Portable		X		X	X			X		X		X						X		X			X	
Fixed		X		X	X			X		X		X						X		X			X	
Belt																								
Flat	X	X	X	X	X			X		X				X	X		X			X			X	
Troughed	X		X	X	X			X		X				X	X		X			X			X	
Portable	X	X	X	X	X			X		X				X	X		X			X			X	
Fixed	X	X	X	X	X			X		X				X	X		X			X			X	
Drag																								
Pusher Bar		X	X	X	X			X		X			X		X					X			X	
Screw	X		X	X	X			X		X			X		X					X			X	X
Floor Chain	X[1]	X		X	X		X			X			X		X					X	X	X		
Overhead Chain	X[1]	X		X	X		X			X			X		X					X	X	X		
Apron																								
Wood Slat	X	X	X	X	X			X		X			X	X	X		X			X			X	
Steel Slat	X	X	X	X	X			X		X			X	X	X		X			X			X	
Ball Transfer		X		X		X					X	X			manual power				X				X	
Bucket Conveyor	X		X		X			X		X			X		X		X			X			X	
Continuous Chain Trolley	X[1]	X		X	X			X		X			X	X	X						X		X	
Slides and Chutes																								
Spiral or Straight																								
Wood	X	X	X		X		X			X			X					X		X			X	
Steel	X	X	X		X		X			X			X					X		X			X	
Vibrating	X		X		X		X	X		X			X		X			X		X			X	
Pneumatic Systems																								
Rigid Tube and Nozzle																								
Bulk loaders	X				X		X			X			X		X					X				X
Bulk unloaders	X				X		X			X			X		X					X				X
Rigid Tube																								
Cylindrical Carrier		X			X		X			X			X		X				X					X
Oval Carrier		X			X		X			X			X		X				X					X
Elevators																								
Freight																								
Electric	X[1]	X	X			X				X			X		X				X				X	
Hand	X[1]	X	X			X				X		X			manual power				X				X	
Hydraulic	X[1]	X	X			X				X			X		X				X				X	
Dumb waiter		X																						
Continuous Lifts																								
Arm		X	X				X	X		X			X		X						X		X	
Tray		X	X				X	X		X			X		X						X		X	

(1) with scoop, bucket etc.

From Ireson, *Factory Planning and Plant Layout*, p. 171.

FIG. 8.27 TABULATION OF PRINCIPAL TYPES OF MATERIALS-HANDLING EQUIPMENT, WITH CHARACTERISTICS AND FEATURES.

factured by a number of different companies, the engineer is faced with the problem of selecting the equipment of a specific manufacturer after he has selected the basic types. Slight differences in design details, sizes, construction, materials, weight, available services, and so on, account for the differences in initial cost of the same basic type from different manufacturers. As far as possible, the engineer should evaluate these differences in terms of initial cost, maintenance and repair, and operating costs, and should base his decision on the engineering economy study. However, many of these differences will not be reducible to monetary terms, and must be handled as irreducibles in the final analysis.

7.7 MATERIALS-HANDLING EQUIPMENT

It is impracticable to attempt to discuss in this volume the many types of handling equipment. Every different kind of equipment has certain merits relative to certain handling problems, and manufacturers are daily adding new designs, new features, and improvements in utility, and are deleting obsolete systems from their lines. The reader is urged to refer to recent publications for up-to-date information on specific handling systems. The periodicals devoted to materials-handling problems,* the trade associations,† and periodicals devoted to factory management‡ are ready sources of current information. Manufacturers' representatives are more than willing to give engineering assistance, cost data, and reference lists of equipment users. Current technical data on all types of handling systems are readily available in the annual *Flow Directory*.

* *Mechanical Handling,* The Louis Cassier Co. Ltd., Dorset House, Stamford St., London, England; *Modern Materials Handling,* 795 Boylston Street, Boston 16, Mass.; *Flow Magazine,* 1240 Ontario Street, Cleveland 13, Ohio; *Flow Directory of Materials Handling Equipment, Machinery and Accessories,* published annually by Flow Magazine.

† American Materials Handling Society, Inc., 638 Phillips Ave., Toledo 12, Ohio; Conveyor Equipment Manufacturers Assoc., 1129 Vermont Ave. N.W., Washington 5, D. C.; Electric Industrial Truck Assoc., 3701 N. Broad St., Philadelphia 40, Penna.; Caster and Floor Truck Manufacturers Assoc., 7 W. Madison St., Chicago 2, Ill.; The Materials Handling Institute, Inc., 1108 Clark Building, Pittsburgh 22, Penna.

‡ *Factory Management and Maintenance,* 330 West 42nd St., New York 18, N. Y.; *Modern Industry,* 400 Madison Ave., New York 17, N. Y.; *Mill and Factory,* 205 E. 42nd St., New York 17, N. Y.

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Journals: The reader should consult one of the reference indexes for articles pertaining to factory planning and materials handling. A great number of important articles appear in the following periodicals:

Advanced Management; American Machinist; American Management Association publications; *Architectural Record; Chemical Industries; Factory Management and Maintenance; Flow Magazine; Industrial Engineering* (A.I.I.E. Journal); *Iron Age; Journal of the Acoustical Society of America; Journal of Industrial Hygiene and Toxicology; Mechanical Engineering; Mill and Factory; Modern Industry; Modern Materials Handling; Modern Management; National Safety News; The Office; Power; Product Engineering.*

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Mr. Moore has long been concerned with standardization and its impact on industry. He initiated and directed a company standards program beginning in 1938 and has been associated with other programs since. In 1950 he developed and introduced an elective course in Industrial Standardization at M.I.T. This course, one of the few such courses to be offered in engineering colleges in America, reflects his own industrial experience, his graduate study in the field, and continued work since. Mr. Moore attended the first seminar in Industrial Standardization presented by Dr. John Gaillard, formerly of the American Standards Association and now a consultant in the field. Mr. Moore has also participated in the development of standards information and activity during visits to a large number of industrial concerns where standards problems have been discussed with standards engineers and business executives throughout the country.

Mr. Moore is a member of the American Standards Association, the Standards Engineers Society, and is also on the staff of Allan H. Mogensen's Work Simplification Conferences at Lake Placid, New York, and Sea Island, Georgia.

SECTION 9

Industrial Standardization

Leo B. Moore

1. WHAT IS STANDARDIZATION?

1.1 STANDARDS TERMS DEFINED

1.1.1 Definition of standard. A standard is anything that we use to measure with. Webster's *New Collegiate Dictionary* defines standard as "1) that which is set up and established by authority as a rule for the measure of quantity, weight, extent, value, or quality, and 2) that which is established by authority, custom, or general consent as a model or example; criterion; test." * Thus in our everyday living we use the word standard in this general sense of measurement, whether we speak of standard of living, standard of conduct, or standard of value. We have a set of measuring sticks in our mind that we use for comparison. Here we are concerned primarily with industrial standards—the kind of measuring sticks we find in a company and its many sections as the day-to-day business goes on.

1.1.2 Types of standards. Because there are so many different standards in industry, they are generally divided into two groups:

1. Technical standards—those standards that apply to the productive phases of the business, such as the materials, parts, products, supplies, manufacturing practices, procedures, and methods, test methods, drafting practices, nomenclature, abbreviations. These specify the what and the how of the business.

2. Managerial standards—those standards that apply to the administrative phases of the business, such as company policy, personnel procedure, accounting

* By permission. From *Webster's New Collegiate Dictionary*, copyright, 1949, 1951, by G. & C. Merriam Co.

systems, expenditure controls, performance evaluation, safe practices, security regulations. These specify the who, when, and why of the business.

1.1.3 Use of descriptive adjectives. Since a clear-cut division does not always exist between technical and managerial standards, some companies make no attempt to separate them. They merely label their standards with appropriate adjectives, such as material standards, safety standards, drafting standards, and the like.

1.1.4 Meaning of standardization. Standardization is the process of setting up standards. It is the organized procedure we go through to decide what the standard will be and then to have it accepted and used by everyone concerned. Sometimes it involves merely writing down the rules that apply to a situation as established by authority; other times it may require discussion and ultimate agreement as established by group consent. The end result is the establishment of a standard. The local fire department states that the fire doors on the spray room will be kept closed, and that becomes a mandatory, managerial standard. The engineers agree after some discussion that CRS is cold-rolled, not corrosive-resistant, steel, and that becomes a voluntary, technical standard.

1.1.5 Similar words. In particular industries or activities, certain other words have come to be accepted as meaning generally the same thing as standard and standardization. Most of these terms are easy to identify if the above definitions and ideas are kept in mind. There are two, however, that warrant definition here: specification and simplification.

1.1.6 Definition of specification. Specification is defined in Webster's *New Collegiate Dictionary* as "a statement containing a minute description or enumeration of particulars, as of terms of a contract, details of construction not shown in an architect's drawing, etc."* In every sense, then, a specification used repeatedly to meet a recurrent problem is a standard. In industry, the term is applied to materials, jobs, products, and so forth, as a matter of custom and should in these instances be considered synonymous with standard. A specification for a house, ship, or other product that is being produced only once is, however, not a standard specification.

1.1.7 Meaning of simplification. Simplification is the reduction of variety by eliminating the unneeded. It is one of the procedures used in standardization and consists of removing from a list of items those that are deemed excessive, unnecessary, or redundant.

* By permission. From *Webster's New Collegiate Dictionary*, copyright, 1949, 1951, by G. & C. Merriam Co.

2. WHO USES STANDARDIZATION?

2.1 SOURCE OF STANDARDS

2.1.1 Levels of standardization. Industrial standards come from so many varied origins that for purposes of general consideration they are classified according to their source and scope. Thus, we have four types or kinds of standards:

1. Company
2. Association and Society
3. National
4. International

As we go down the list, it is apparent that the standard is effective in a larger and larger area. Consequently, its preparation and approval become bigger and bigger problems. For that reason, these groupings are frequently referred to as the "levels of standardization" in considering the field as a whole.

2.1.2 Interchange of standards. If any level can be held as the most important, it is the company, for there are no industrial standards of any significance except those accepted and used by the companies. The companies are the consumers. Delivered to them every year are hundreds of standards from the organizations on each of these levels. In addition, the companies are pre-

paring standards for their own use, and to some extent sharing them with other companies and receiving standards in return. There is no restriction either in the amount or the kind. Every level feels free to concentrate or to expand its standardization activity and to work with other levels. This interchange and interplay mean an ever-increasing supply of standards and an ever-expanding coverage for them.

2.2 COMPANY ACTIVITY

2.2.1 Informal programs. Every company uses standards of some sort, but not every company has a formal standards program. Those that do not have an organized program tend to inherit or absorb standards from around them and to employ those that fit their operations or are required by them. Most often this activity is carried on by individuals in the company as a simple matter of "common sense," without fanfare or publicity. The companies in this group by far outnumber those that employ standardization on an organized basis. Some of these companies feel that they do not have the time, money, or personnel to spare from more pressing tasks. Many others have never given any consideration to establishing a formal standards program.

2.2.2 Formal programs. Standardization is not for the exclusive benefit of the large company that can indulge in it and indulge it. A list of the companies active in standardization is not a "Who's Who" of American industry by any manner or means. Whether large or small, the company executives have the same decision to make: "Do we organize our present use of standards and receive the additional benefits of such activity, or do we leave well enough alone?" The extent of the activity to begin with, and its subsequent growth, are matters of policy for each company. To help in answering these questions, a more detailed treatment is given to the company program in Art. 4.

2.3 ASSOCIATION AND SOCIETY

2.3.1 Purpose. Much of the work of the company standards program will extend beyond the organizational and geographical boundaries of the company itself. Many decisions will require cooperation and coordination with other companies. The natural vehicles for such participation are the trade associations and the professional and technical societies, with their industry-wide interest and membership. For that reason, many of these organizations are urged by their membership to maintain an active interest in standardization, at least to the extent that it affects their operations.

2.3.2 Procedure. The usual approach to standardization used by associations and societies is to establish a standards committee that (1) reviews the opportunity for standardization, (2) appoints investigating sub-committees as needed, (3) presents the recommended standard to the membership for approval, and (4) publishes it for general use.

2.3.3 Extent. At least 450 of the 3,000 associations and technical societies in the United States are actively concerned with matters of standardization. A description of these activities, as well as other pertinent information, has been prepared by Robert A. Martino for each of these organizations and is available from the Superintendent of Documents, Washington, D. C.*

2.3.4 National Electrical Manufacturers Association. A brief account of the work of NEMA should be of interest, since electrical products are so much a part of our every-day life. NEMA is a trade association of about 520 manufacturers of equipment and apparatus used for the generation, transmission, distribution, and utilization of electric power. NEMA may be considered as an aggregation of product subdivisions called Sections, each representing manu-

* Robert A. Martino, *Standardization Activities of National Technical and Trade Organizations* (Washington, D. C.: National Bureau of Standards Misc. Pub. M169, 1941).

facturers of certain classes of products, such as motors and generators, steam and hydraulic turbines, transformers, wire and cable, switchgear, industrial controls, ranges, water heaters, and domestic appliances.

The standardization activities of NEMA are guided by policies established by the Board of Governors. The following general statement of NEMA policy appears as a foreword to every NEMA standard:

> National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for its particular need. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or non-member from manufacturing or selling products not conforming to the standards.

The NEMA Bylaws define a NEMA standard as follows:

> A Standard of the National Electrical Manufacturers Association defines a product, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, quality, rating, testing and the service for which designed.

Correlating the standardization activities of NEMA is the Codes and Standards Committee, which supervises these activities by:

1. Reviewing for approval, or for other appropriate action, all proposed standards, reports, or technical documents, which are to be issued as having official NEMA approval, and

2. Designating the personnel and supervising the activities of NEMA representation on all technical committees working with other standardizing organizations, thereby assuring adequate representation and proper consideration of the diversified interests of the electrical manufacturer.

In general, a NEMA standard originates in its product "Sections," where a committee develops the standard, and, after approval of the Section as a whole, it is referred to the Codes and Standards Committee for complete review and final approval.

NEMA has approximately 125 current publications covering standards on such varied items as brushes, terminals, sockets, lamp bases, wires, cables, insulators, transformers, circuit breakers, measuring instruments, electrical equipment, machinery and controls, and safety codes.

NEMA is in contact with some 70 associations and organizations for the purpose of cooperating in joint standardization projects of mutual interest, such as:

(a) Edison Electric Institute and the Association of Edison Illuminating Companies (standards for various electrical products used in the generation, transmission, and distribution of electrical energy).

(b) American Welding Society (qualification of welding operators).

(c) Joint Electron Tube Engineering Council (electron tube standardization).

(d) National Machine Tool Builders Association (provisions for wiring and control of motors for machine tools and standardization of motors and other electrical equipment as applied to machine tools).

(e) American Standards Association, Inc. (development, approval, and promotion of American standards of interest to electrical manufacturers).

(f) National Fire Protection Association (the periodic revision of the National Electrical Code and other safety standards).

NEMA also cooperates with various governmental agencies, such as the Electrical Supplies Committee of the General Services Administration, Underwriters' Laboratories, Inc., and other testing organizations, and the Canadian Standards Association.

2.3.5 American Society for Testing Materials. A brief description of the work of ASTM should also be of interest, since the standards of this organization

have found their way into every company in the country. ASTM was organized in 1898 and formally incorporated in 1902 as a national technical society. Its specific purpose is "the promotion of knowledge of the materials of engineering, and the standardization of specifications and the methods of testing." Over 1,000 technical committees are responsible for the development of standard specifications and tests and for keeping them up to date. The Society's work is advanced by the presentation and subsequent publication of technical data in the form of papers, reports, and discussions. In its membership of over 7,300 are represented (1) producers of raw materials and semifinished and finished products, (2) consumers of materials, and (3) a general-interest group comprising engineers, scientists, educators, testing experts, research workers, and so forth. Membership is held by individuals, companies, associations and technical societies, governmental departments, schools, and libraries.

ASTM standardization applied to methods of testing and analysis recognizes that the properties shown by a material are dependent to a large extent upon the method of determination, and, in order that comparative results may be secured in widely scattered laboratories, that standardized procedures are essential. ASTM is splendidly equipped to develop standard test methods, because on its 80 main technical and administrative committees and their hundreds of sections are outstanding experts of the country in their technical fields.

To develop specifications, as well, the ASTM committee organization is very well adapted, for each committee is made up of producers who are familiar with the limitations of the manufacturing processes, and of consumers who are fully acquainted with the requirements of the various uses to which the material is put. Before a standard is finally adopted by ASTM it has been given a rigorous examination in the committees, by the Society as a whole, and through actual use during the period of publication as a tentative standard, since tentatives are recognized as embodying the latest thoughts and practices and are widely used throughout industry.

A great amount of authoritative data concerning materials is brought out by the Society, either as an adjunct to its standardization work, or as the result of independent research. In fact, before any standardization is possible, some research is necessary. It is only after data from reliable tests are available that intelligent recommendations can be made in regard to the material in question. ASTM has over 100 separate research projects supporting its standardization work. The 1,900 ASTM Standards are issued in a book of seven parts:

Part 1—Ferrous Metals
Part 2—Non-Ferrous Metals
Part 3—Cement, Concrete, Ceramics, Thermal Insulation, Road Materials, Waterproofing, Soils
Part 4—Paint, Naval Stores, Wood
Part 5—Fuels, Petroleum, Aromatic Hydrocarbons
Part 6—Electrical Insulation, Plastics, Rubber
Part 7—Adhesives, Shipping Containers, Paper, Soap, Water, Textiles

ASTM collaborates with many organizations such as: American Society of Civil Engineers, American Society for Engineering Education, American Society of Heating and Ventilating Engineers, American Society of Lubrication Engineers, The American Society of Mechanical Engineers, American Society for Metals, American Standards Association, Inc., Society of Automotive Engineers, American Foundrymen's Society, and dozens of leading trade associations and other technical groups, many branches of the government (particularly the National Bureau of Standards), and all branches of the armed services.

2.4 NATIONAL STANDARDIZATION

2.4.1 Importance of the national work. A centralizing force is essential to coordinate and correlate the standards work of the hundreds of companies, associations, and groups in the

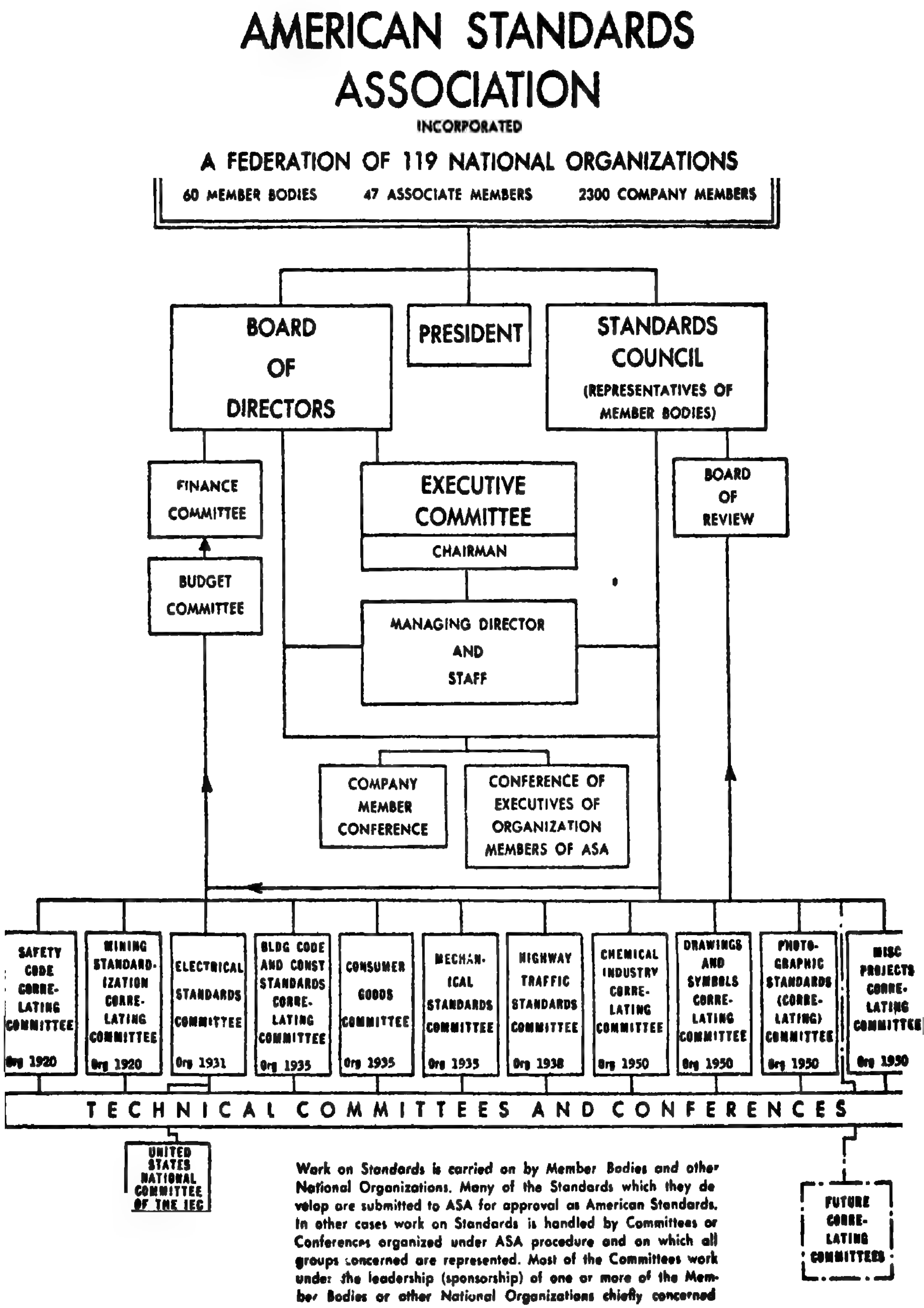


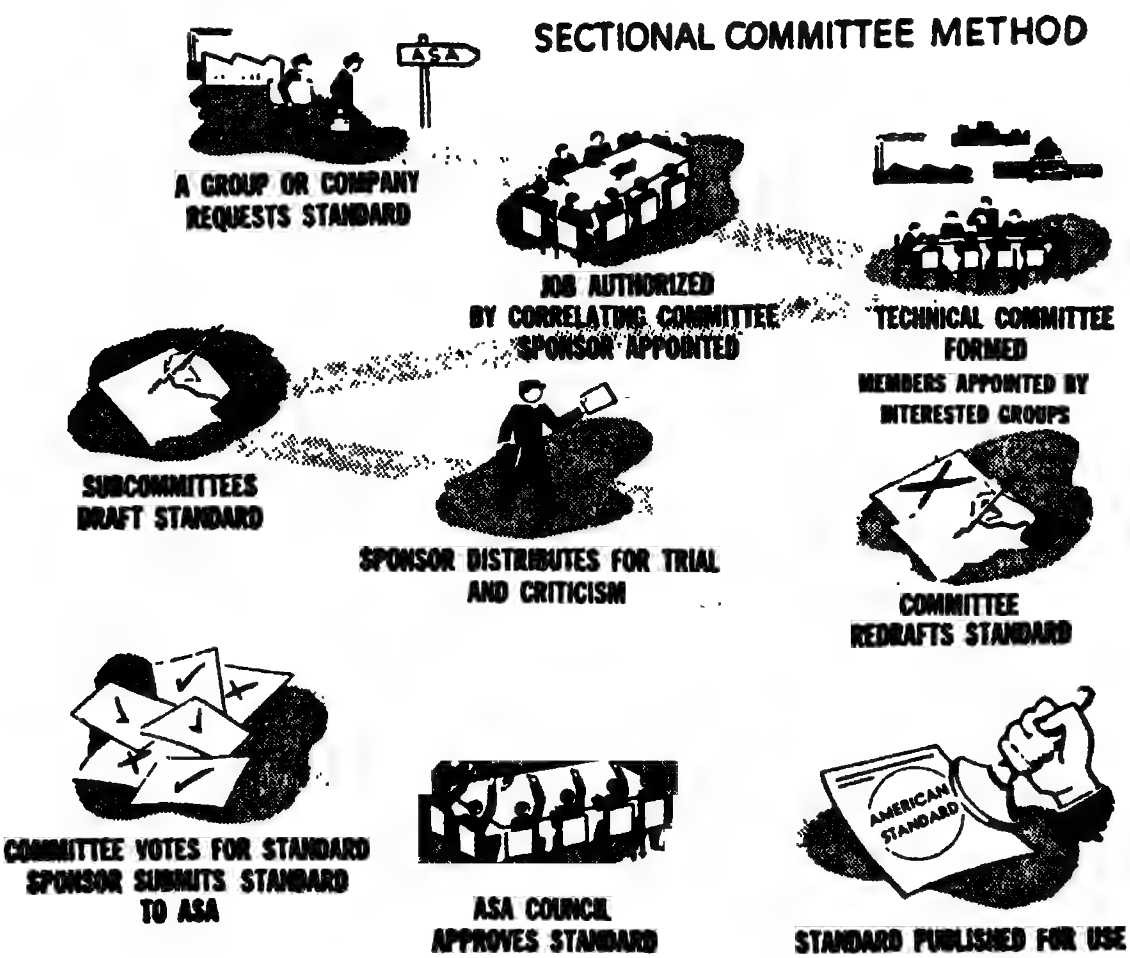
FIG. 9.1 THE AMERICAN STANDARDS ASSOCIATION—THE SCOPE OF THE WORK OF THE ASA IS REFLECTED IN ITS ORGANIZATION.

country, to prevent duplication of effort, and to bring together all interested parties. For the same reasons and in the same ways that companies seek assistance of the association and society, a vehicle is needed to solve standards problems on a nationwide basis.

2.4.2 American Standards Association, Inc. The ASA was set up in 1918 (then called the American Engineering Standards Committee) to serve as a central, national clearinghouse for standardization work in the United States (see Fig. 9.1). It is a privately financed federation of over 100 national trade associations, professional societies, and consumer organizations, with a membership of more than 2,000 companies representing a cross section of commerce and industry. The ASA does not initiate standards; rather, it provides facilities and procedures to all groups working in the public interest for the development of voluntary American standards. ASA lends tremendous assistance in promoting the use of these standards.

Through its organization and procedures, the ASA establishes the policy, methods, and machinery for the development and approval of American standards. Final approval rests in the Standards Council, which has jurisdiction over rules of procedure and the personnel of committees, as well as over the scope of the projects under consideration. Reporting directly to the Standards Council and acting on its behalf are Correlating Committees which directly administer and supervise the development of American standards. The procedures employed by ASA committees are truly democratic. Every group sub-

FIG. 9.2 ASA PROCEDURE—SECTIONAL COMMITTEE METHOD.



Courtesy of the American Standards Association.

stantially concerned with a standard is guaranteed the right to participate in deciding what the provisions of a standard shall be. Decisions are not made by simple majority vote, but rather by the concensus principle. Every effort is made to thrash matters out so thoroughly that a unanimous decision can be reached. The aim is national acceptance for American standards.

The Sectional Committee Method, shown in Fig. 9.2, is one of the alternate procedures employed by ASA to meet the variety of conditions that exist in standardization work. Under these procedures more than 1,100 American standards and American safety standards have been developed by representatives of industry, government, labor, distributors, and consumer organizations.

2.4.3 Government agencies. The United States government has for many years been involved in phases of standards work and has made important contributions to the standardization picture in this country.

2.4.3.1 National Bureau of Standards. According to the provisions of the Constitution, Congress has authority over weights and measures. After years of delay and an increasing demand for decisions and action, the Bureau of Standards was set up in 1901. The functions outlined in the enabling act were restated more explicitly in Public Law 619, 81st Congress, as follows:

> Sec. 2. The Secretary of Commerce (hereinafter referred to as the 'Secretary') is authorized to undertake the following functions:
>
> (a) The custody, maintenance, and development of the national standards of measurement, and the provision of means and methods for making measurements consistent with those standards, including the comparison of standards used in scientific investigations, engineering, manufacturing, commerce, and educational institutions with the standards adopted or recognized by the Government.
>
> (b) The determination of physical constants and properties of materials when such data are of great importance to scientific or manufacturing interests and are not to be obtained of sufficient accuracy elsewhere.
>
> (c) The development of methods for testing materials, mechanisms, and structures, and the testing of materials, supplies, and equipment, including items purchased for use of Government departments and independent establishments.
>
> (d) Cooperation with other governmental agencies and with private organizations in the establishment of standard practices, incorporated in codes and specifications.
>
> (e) Advisory service to Government agencies on scientific and technical problems.
>
> (f) Invention and development of devices to serve special needs of the Government.

The Bureau is authorized to "exercise its functions for the Government of the United States, for any State or municipal government within the United States, or for any scientific society, educational institution, firm, corporation, or individual within the United States engaged in manufacturing or other pursuits requiring the use of standards or standard measuring instruments." On this broad base of research and testing, the Bureau through the years has built up its activities and has performed excellent service for the country. It has become recognized as the principal agency of the federal government for research in physics, mathematics, chemistry, and engineering. It is concerned not only with the basic standards of mass, length, and time, but also with a wide variety of other standards in electricity, optics, heat and power, atomic physics, chemistry, mechanics and sound, organic and fibrous materials, metallurgy, mineral products, building technology, applied mathematics, electronics, and radio propagation. In each of these areas, the Bureau has designed its functions to establish standards of measurement, quality, performance, and practice.

Although the Bureau has no regulatory power, it has gained a high position in fundamental standards work through the high standard it has set for its work, the cooperation with individuals and

groups throughout the country, and the publication of its findings.

2.4.3.2 Federal specifications. The federal specifications program was initiated in 1921 and has operated under various procedures since that time. It was formally constituted as an element of the supply process under the direction of the Procurement Division, U. S. Treasury Department, in 1945. On August 9 of that year, the Director of Procurement issued Circular Letter A-99, establishing the Federal Specifications Board, to the heads of federal agencies. The Board was charged "with the preparation and revision of purchase specifications for supplies used by executive departments and establishments."

Representatives of the executive agencies concerned with supply, and the following independent agencies—Veterans, Federal Security, and Federal Works—made up the membership of the Board. The Director of the National Bureau of Standards was appointed Chairman, and the Director of the (now) Standards Division, Federal Supply Service, was appointed Executive Vice Chairman.

Approximately 78 technical committees drawing membership from all government agencies were created to develop federal specifications under the Board's direction. Under the technical committee method of developing federal specifications, preliminary drafts were circulated not only to government agencies, but also to representative manufacturers and nationally known technical societies for comment.

With the passage of the Federal Property and Administrative Services Act of 1949 (Public Law 152, 81st Congress), the functions of the Bureau of Federal Supply (formerly the Procurement Division), together with the responsibility for developing federal specifications, were transferred to the General Services Administration. The Bureau of Federal Supply was designated the Federal Supply Service of the General Services Administration.

The Specifications Branch of the Standards Division, FSS, handled the coordination of federal specifications technical committee activities and provided each committee with a technical assistant to act as adviser, and to develop and write specification drafts and brief abstracts of government department comment.

In April, 1952, the Administrator of General Services abolished various boards and committees, among them the Federal Specifications Board, and established an over-all board to "promote sound personal property management practices in Government." This latter board is known as the Federal Supply Board.

A new procedure, known as the Assigned Agency Method of preparing federal specifications, was inaugurated. Under this method, agencies having prime technical and procurement interests in specific commodities are assigned the project of preparing specifications for those commodities. Assignments are made by the Federal Supply Service, General Services Administration, with the concurrence of the agencies involved. Federal specifications now numbering approximately 2,600 are mandatory for use by all federal agencies.

Prior to the widespread availability of federal specifications, each federal agency found it necessary to establish its own specifications for the items it purchased. Since the inception of the specifications program, the National Bureau of Standards, as a result of its research activities, has rendered a valuable technical service in the development of both departmental and federal specifications. It has contributed much technical leadership in the federal specifications program.

Working in conjunction with the Federal Supply Service, the National Bureau of Standards conducts research and developmental work on the federal specifications program. It also collaborates in the development of test methods and conducts acceptance testing on the more complicated materials requiring extensive equipment and testing facilities.

Because of the extensive volume of government purchases, federal specifications have had considerable influence upon American industry. They are used

TABLE 9.1 VARIETY REDUCTION—EXAMPLES OF THE EFFECT OF SIMPLIFIED PRACTICE RECOMMENDATIONS (S.P.R.)*

Title	S.P.R. No.	S.P.R. Year	Reduction in variety From	Reduction in variety To	Per cent reduction
Adhesive plaster	85	47	26	15	42
Bell-bottom screw jacks	97	47	78	27	78
Cans for fruits and vegetables	155	49	200	32	84
Cast-iron radiators	174	47	33	17	49
Clinical utensils (aluminum and steel)	240	50	(1)	52	—
Coffee grinds	231	48	Dozens	3	—
Convectors	238	50	1,000,000	1,002	99.8
Copper and copper-alloy rod	241	50	(1)	103	—
Cotton jersey cloth and tubing for work gloves	194	48	11	3	73
Cut-tacks and small cut nails	47	49	428 sizes	185	57
			423 pks.	127	70
Delivery cases for milk bottles	236	49	Dozens	5	—
Eaves trough, conductor pipe and fittings	29	49	110	79	28
Ferrous range boilers, and tanks	8	50	130	13	90
Files and rasps	6	47	661	377	43
Flat veneer products, spoons, forks, etc.	230	48	29	8	72
Galvanized woven wire fencing	9	47	2,072	200	70
Glass containers for cottage cheese	148	47	24	4	80
Grinding wheels	45	47	715,200	254,400	64
Heavy forged hand tools	17	47	49	21	57
Hospital & institutional cotton textiles	74	49	459	26	94
Iron body valves (pressure ratings)	184	47	13	4	75
Loaded paper shot shells	31	50	4,067	262	94
Low-pressure lubricating devices	232	48	428	274	36
Low-pressure thermostatic radiator traps and float-and-thermostatic traps	244	51	(1)	9	—
Medical and surgical hypodermic needles	224	47	55	22	60
Metal-cutting band saws	214	48	127	60	53
Pipe fittings (iron, brass and bronze)	185	47	8,566	2,969	65
Pipes, ducts & fittings (warm air heating)	207	49	5,080	1,225	78
Plumbing fixture fittings (housing)	227	47	(1) finish	3	—
Rotary files and burs	233	48	2,000	468	72
Steel reinforcing bars	26	50	32	11	66
Surgical dressings	133	49	5,000	61	99
Surgical gauze	86	47	70	26	63
Surgical sutures	239	50	(1)	28	—
Tank-mounted air compressors (¼ to 10 horsepower)	202	48	347	12	96
Unorificed radiator supply valves	243	51	(1)	5	—
Vinyl and pyroxylin coated cotton fabrics	242	51	(vinyl) 76	20	73.7
			(Pyrox.) 88	25	71.6
Vises (machinists' and related kinds)	229	48	14	8	43
Wire rope	198	50	352	182	48
Welded chain	100	47	1,831	1,214	64

* Courtesy Commodity Standards Division.
Note (1). Too numerous to count.

not only by the federal government, but by state and local governments as well, and in many instances by industry either in their original or in modified form.

2.4.3.3 Simplified practice. As part of Herbert Hoover's program of waste-elimination in industry, the Division of Simplified Practice was established in the National Bureau of Standards, U. S. Department of Commerce, in 1921. The purpose of the Division was to establish procedures and facilities that would bring together all interested parties in a nationwide program to simplify lines of manufactured products, as, for example, an 84 per cent reduction in sizes and varieties of cans for fruits and vegetables, from 200 to 32. This was a voluntary action on the part of all groups concerned—manufacturers, distributors and consumers—with the Division acting as a center of assistance. The Division serves as publisher of the promulgated Simplified Practice Recommendations. More than 245 such recommendations have been issued, covering products in many fields. The Division, still operating under these principles of voluntary and complete representation and decision, is now a part of the Commodity Standards Division in the Department's Office of Industry and Commerce. A list of effective Simplified Practice Recommendations is available, together with examples of nonessential variety, such as those shown in Table 9.1.

2.4.3.4 Commercial standards. In 1927, the Division of Trade Standards, patterned after the Division of Simplified Practice, was organized in the National Bureau of Standards to assist industry in the establishment of standards of quality of manufactured goods. The published standards are called commercial standards.

Commercial standards cover terminology, types, classifications, grades, sizes, and use characteristics of manufactured products, and describe standard methods of test, rating, certification, and labeling. Their purpose is to provide uniform bases for fair competition, and to assist industry in maintaining quality that will command the respect of purchasers.

The function of the Department of Commerce in the establishment of commercial standards is that of a coordinating and fact-finding agency to assist in ascertaining the desires of all concerned. Commercial standards are developed only upon written request of interested parties. The promulgation of a standard developed through the resulting cooperative action is dependent upon written acceptances from the trade representing a satisfactory volume of business in the commodity covered. Adherence to commercial standards by the industry is entirely voluntary, but when guarantees of conformance are made by the manufacturer or seller, that guarantee is a part of the sales contract. A list of commercial standards currently in effect may be obtained on request from the U. S. Department of Commerce, Washington 25, D. C.

2.4.4 Sister nations. Just as the ASA was created by industry to serve as a central national clearinghouse for standardization work in the United States, so too have national standards bodies been organized in 33 foreign countries listed in Table 9.2. Some of them are in-

TABLE 9.2 FOREIGN COUNTRIES HAVING NATIONAL STANDARDIZATION BODIES

Australia	Denmark	Italy	Rumania
Austria	Finland	Mexico	Spain
Belgium	France	Netherlands	Switzerland
Brazil	Germany	New Zealand	Sweden
Canada	Hungary	Norway	Union of South Africa
Chile	India	Pakistan	United Kingdom
China	Ireland	Poland	Uruguay
Czechoslovakia	Israel	Portugal	USSR
		Yugoslavia	

timately linked to their governments through financial support, representation, and direction, but all aid materially in coordinating the industrial standards of their nations by avoiding duplication, eliminating conflict, and encouraging use of these standards.

2.5 INTERNATIONAL STANDARDIZATION

2.5.1 Importance of international work. The highest standardization work is that accomplished on an international level. The recognition of the interdependence of nations and of the importance of their interrelationships urges such work upon us, but difficulties of national language, customs, and pride make for almost insurmountable obstacles. Although the amount of standardization on an international level has been limited, it has nevertheless been of major importance because of its wide influence.

2.5.2 Weights and measures. In 1875, the Metric Convention established ways and means for international agreement on scientific data such as nomenclature, symbols, physical constants, temperature scales, and definitions, in addition to weights and measures. The results of its regular meetings have done much to facilitate the exchange of scientific data and technical information.

2.5.3 Electrical equipment. In 1904, the St. Louis Electrical Congress recommended the formation of an organization for worldwide standardization in the electrical field. As a result of this suggestion, the International Electrotechnical Commission was organized in 1906. The Commission, through its committee meetings, has established standards for international symbols, resistance measurements, rules for rating machinery, nomenclature, voltages, heavy current systems, and motor specifications.

2.5.4 Illumination. The International Commission on Illumination, started in 1913, has made some attempts at standardization of lighting systems and associated technical problems. The work has been limited but has included definitions of luminous intensity, fundamental quantities used in illumination and photometry, and uniform practices in lighting.

2.5.5 Industrial practices. In spite of the limited success of the technical bodies in the international standardization of scientific data, and in spite of the diverse problems of the different industrial nations, the national bodies of many countries have continually pressed for international cooperation and standardization of industrial activities.

2.5.5.1 International Federation of National Standardizing Bodies (ISA). After a series of meetings in the early 1920's, the national bodies of 21 nations joined in an International Federation, with headquarters in Basle, Switzerland. By 1939, work on 47 projects was under way, and substantial progress had been made toward securing international uniformity in such diverse fields as photographic and acoustical standards, documentation standards for libraries (including microfilm techniques), limit systems for machine parts to provide for interchangeable fits, inch-millimeter conversion ratio, preferred numbers, paper sizes, and film standardization.

2.5.5.2 Regional cooperation. For many years countries that are linked by common language, boundaries, and commerce have engaged in joint standardization. In Europe, prior to World War II, the Dutch, Swiss, Swedish, Czechoslovakian, Austrian, and German standards bodies cooperated very closely. The same has been true of Canada and the United States, the United States and the Latin-American countries, and the United Kingdom, Canada, and the United States. In 1948, the latter group reached an agreement for standard screw threads to apply in each of the three countries. During World War II, these countries worked closely together on standardization matters and formed what was known as the United Nations Standards Coordinating Committee as a temporary body for international cooperation. Since this was prior to the end of the war and to the formation of the United Nations Organization, the words "United Nations" in the title of

the UNSCC do not indicate any affiliation with the UN.

2.5.5.3 International Organization for Standardization (ISO). In 1947, in Zurich, Switzerland, the first general assembly was held of the International Organization for Standardization (ISO), with a membership of the national bodies of 26 countries. The organization agreed to have as its official languages English, French, and Russian, and in many other respects to pattern its operation after the United Nations. The governing bodies of the ISO are the General Assembly, constituted by a meeting of the delegates nominated by the member bodies, and the Council, consisting of the President of the ISO and a representative from each of ten member bodies. At least five member nations must indicate their interest in a project before it is initiated. Acceptance of the resulting standards is voluntary. At its inception, the ISO agreed to assume and resume the work of the pre-war ISA and the war-born United Nations Standards Coordinating Committee. This work, coupled with the programs already offered by the member nations, means that there are 77 projects before the ISO, ranging from automobile parts to textiles.

3. WHAT GOOD IS STANDARDIZATION?

3.1 VALUE OF STANDARDIZATION

Every person in industry today is generally aware of the benefits of standardization. Increasing the use of standard or interchangeable parts in a line of products has become a routine economy with many. This is only the beginning of what standardization can do for a company and an industry. More numerous and even greater advantages may be obtained from standardization when the program is effectively organized on a company-wide basis. Some of these benefits in different parts of a business are here detailed.

3.2 BENEFITS IN PURCHASING

3.2.1 Establishment of specifications for materials, parts, and supplies

a. Routinizes purchasing activities.

b. Makes every purchase truly competitive

c. Ehminates buying "special" lots.

d. Eliminates costly brand names.

e. Promotes understanding with suppliers.

f. Reduces returns.

g. Simplifies purchase orders.

h. Eliminates explanatory letters, telephone calls, sketches, conferences.

i. Simplifies receiving and storing procedure.

j. Simplifies requisition forms and procedure.

3.2.2 Reduction of variety of materials, parts, and supplies.

a. Permits buying of larger quantities at lower prices.

b. Permits making of contract arrangements for a production period.

c. Reduces investment in inventory.

d. Reduces storage space, facilities, and materials handling.

e. Permits routinizing of office methods, paper, and procedures.

3.2.3 Simplifying routine purchases and regular procedures.

a. Frees personnel for additional activities usually bypassed.

b. Permits more adequate investigation of irregular purchases of equipment, services, and supplies.

c. Increases the effectiveness of purchasing personnel.

d. Contributes to higher morale of the department.

e. Reduces error and conflict.

3.3 BENEFITS IN ENGINEERING

3.3.1 Establishment of specifications for materials, parts, and supplies.

a. Reduces decisions in research and design.

b. Permits investigation and evaluation of substitutes.

c. Accumulates dependable performance data.

d. Permits employment of standard drafting procedures.

e. Reveals critical characteristics and their influences.

f. Permits employment of standard production engineering practices and procedures.

3.3.2 Establishment of standard engineering practices and procedures.

a. Reduces confusion, error, and misunderstanding.

b. Permits establishment and evaluation of uniform test procedures and methods.

c. Aids training of personnel.

d. Permits investigation and evaluation of new techniques.

e. Accumulates data peculiar to the operations of the company.

f. Tends to make design decisions more practical, efficient, and economical.

g. Gives direction to research activity and assures that results of research are put to use.

h. Helps to eliminate usually accepted trade practices that impede progress.

3.4 BENEFITS IN MANUFACTURING

3.4.1 Reduction in number and variety of manufactured products.

a. Makes longer runs possible.

b. Reduces equipment changeover and downtime.

c. Makes specialized tools, equipment, and methods possible and justifiable.

d. Reduces process inventory and materials handling.

e. Simplifies production record-keeping and scheduling.

f. Simplifies personnel training.

3.4.2 Establishment of standard processes and procedures.

a. Permits more adequate production control.

b. Permits more effective quality control.

c. Aids in the establishment of uniform test and inspection technique.

d. Provides opportunity for study and evaluation of improved production techniques.

e. Permits accumulation of production data peculiar to the company.

f. Reduces confusion, error, and misunderstanding.

3.5 BENEFITS IN MARKETING

3.5.1 Reduction in number and variety of product line.

a. Permits concentration of sales effort on profitable items.

b. Makes for easier installation and service.

c. Simplifies problem of replacement and repair.

d. Reduces conflict between production and sales.

e. Promotes understanding of production capabilities.

f. Reduces special demands on production facilities.

g. Permits comparison with competitors' products.

h. Establishes standard for consumer acceptance and approval.

3.5.2 Establishment of standard sales procedures and techniques.

a. Permits better handling of customer requirements.

b. Improves relations with the customer.

c. Simplifies sales training.

d. Eliminates confusion, error, and conflict.

e. Permits comparison of sales effort by individuals or areas.

f. Simplifies sales paperwork.

3.6 BENEFITS IN OFFICE MANAGEMENT

3.6.1 Reduction in number and variety of forms.

a. Eliminates unnecessary record-keeping and report-writing.

b. Permits establishment of regular and routine activity.

c. Makes specialized equipment possible and justifiable.

d. Simplifies personnel training.

e. Reduces inventory, storage, and handling problems.

3.6.2 Establishment of standard office procedures and practices.

a. Permits institution of methods of measurement, control, and improvement of paperwork.

b. Permits investigation and improvement of existing forms.

c. Eliminates confusion, error, and misunderstanding.

d. Provides opportunity for investigation and evaluation of equipment and methods improvement.

e. Aids in reducing uncertainty, pressure, and fatigue.

f. Increases the morale of the office.

3.7 BENEFITS IN TOP MANAGEMENT

3.7.1 Establishment of operating standards for all sections of the business.

a. Promotes employment of the "exception principle."

b. Permits comparison of departmental and over-all operations.

c. Removes need for recurring decisions on routine problems.

d. Frees executive time for most important decisions.

e. Provides opportunity for development of middle management.

f. Improves morale.

3.7.2 Establishment of standard policies for all sections of the business.

a. Improves industrial and customer relations.

b. Replaces doubt with decision.

c. Provides goals and objectives for middle management.

d. Establishes bases for management improvement programs.

e. Provides opportunity for review and evaluation.

f. Promotes coordination and control of the whole business.

g. Promotes harmony in the whole enterprise.

3.8 DOLLAR SAVINGS FROM STANDARDIZATION

3.8.1 ASA survey. The ASA undertook a survey representing 140 documented case studies, covering 81 industries and industrial products, for the purpose of compiling proof in terms of dollars or percentages of net savings attributable to standardization.

3.8.2 General findings. A check list returned by 61 companies show these main fields where savings have been achieved through standardization:

1. The greatest number (over 75 per cent) derived savings from reduced inventories of materials, parts and end products. Nearly the same number (72 per cent) listed purchasing "larger quantities of fewer items" and use, in engineering, of "accepted standard specifications" vs. "special specifications" as sources of savings

2. The next greatest number (67 per cent) gave "buying most economical quantities," "use of industry, national, or other standard specifications," and "variety reduction and interchangeability" as sources from which they had derived savings.

3. With the exception of economies derived from modular coordination the remaining items of the check list were marked by from 26 per cent to 54 per cent of those returning the list. Of these items, "fewer materials and smaller variety of parts" and "minimum storage and warehousing costs," stood highest; "economies of special-purpose machines" was lowest.

4. Ten per cent indicated that they had derived savings from "modular coordination."

5. Forty per cent of the lists returned gave credit to standardization for "improved inter-departmental coordination."*

3.8.3 Specific cases. Some specific examples of savings given by these companies are listed below. In fairness, not all the best examples have been chosen.

* From "Dollar Savings Through Standards," published by the American Standards Association.

But the fact that savings exist and are known, no matter their extent, is helpful.

Figures show that in one year's output of American automobiles over $800,000,000 was saved for the manufacturers, and of course in cost to the public, because of the large number of minor parts that have been standardized.

A large motor manufacturer reported that a record was kept of the number of hexagonal head screws used in the various models which they built. The reduction in cost after standardization was $52,758.96 in one year.

Ball bearing and electrical equipment manufacturers state that SAE standards have reduced production costs over 20 per cent.

A well-known case of a similar kind is that of an aircraft manufacturer who saved $268 per plane by substituting industry standards for bolts in the place of special company standards.

So many intangibles are involved that savings can only be "guesstimated." "Factory costs are reduced, probably, by 1 to 3 per cent" writes a large manufacturer of type-setting machinery.

Standards are really the life blood of motion pictures, for without them there would be no motion picture industry.

There is no doubt that standardization in the electric utility business is responsible for many of the fine economies which we now enjoy. Also, it has made it possible for us to have more strict construction standards which results in carrying a minimum of different kinds and types of materials in our storerooms.

We regret that we have no information which will allow us to make an appraisal of the benefits in terms of dollars but we inherently know that they are substantial with us as with all companies employing the principles of standardization.

Standardization of stationery and printing by a small eastern railroad was reported, in 1944, to have reduced the cost from $110,000 to $65,000 a year, a saving of 41 per cent.

In a paper manufacturing establishment an increase in "percentage of perfect" from 92 per cent to 96 per cent was achieved in seven months as a result of the application of quality control standards.

In a textile machinery factory, stores inventories were reduced 9 per cent within a space of four months.

In a factory manufacturing cooking utensils, the reduction of storage and warehousing costs amounted to $184,716.*

4. HOW CAN STANDARDIZATION BE USED?

4.1 COMPANY PROGRAM

Standardization starts and ends in the individual company and in its everyday operations. The extent of its use is determined partly by the size of the company, but mostly by the attitude of its personnel. And of all its personnel the top executives of the company exert the main influence—influence on its emphasis, organization, activity, and support. Consequently, there are as many programs as there are companies, and it would be foolhardy here to state specifically that any particular company should do this or that. Rather, the possibilities for its use within a given company should be explored and pursued.

4.2 PROGRAM LIMITS

Since standardization has its limitations in our economic society, corresponding limits should be placed on standardization, particularly within the company. What those limits are is determined by the specific situation, but the items in the following list should at least be given consideration:

1. The customer must benefit as well as the manufacturer.
2. The product should be standardized—not the commercial procedures or prices.
3. The emphasis will be on physical and mechanical standards rather than on design characteristics.
4. Quality is the key objective—making possible the culling out of substandard equipment.

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* From "Dollar Savings Through Standards."

TABLE 9.3 GETTING STARTED—SEVEN WAYS INTO A STANDARDS PROGRAM*

1. Encourage and support efforts to promote standardization within your industry.

2. Review with suppliers the possibilities for purchasing items in fewer varieties but in greater volume.

3. Enlist the active interest of all plant people in company standardization efforts.

4. Get your own customers to agree on changes in the products you sell to permit wider use of interchangeable and identical components.

5. Set up an alert organization to tackle the task of eliminating superfluous variety and to guarantee continuous, careful scrutiny of this problem.

6. Study opportunities for standardization, not only in the products you sell but also in such purchased materials as maintenance and first-aid supplies.

7. Start now, if only in a small way, to push standardization in your plant so that its benefits will be yours when the business of making a profit really gets tough.

* Reprinted from the June 15, 1946 issue of *Modern Industry*.

5. At no time shall standardization involve an agreement not to build anything and everything and thus limit a justifiable choice on the part of purchasers.

6. Engineering designs must not be frozen and thus prevent improvements such as reduction of size, improvement of operating characteristics, etc. This is usually assured by the standardization of maximums or minimums, but not both. There is only the economic ceiling to the degree of quality which a manufacturer can supply. As that quality increases, a new standard may more nearly describe a standard product and the standard itself should be changed.

7. In any simplification by combination, the standard adopted shall include the qualities and use features of the line eliminated.

8. Support standardization with price benefits—with price additions consistent with costs for special features, and with service benefits such as exchange plans.

9. Work constantly so to define and promote product uses and to simplify manufacture, design, and distribution on preferred sizes and types that the economies of volume production can be realized.

10. Encourage the sale of those specials which promise a reasonable volume in order to meet necessary user requirements and to stimulate design improvements.

11. In manufacture within the factory, achieve simplification by maximum use of common parts, employment of methods using common tools, utilization of preferred number series for fewer sizes, and standardization of suppliers' materials and parts.*

4.3 STARTING POINT

Every company has a set of standards, even though that term may not be applied to them. The purchasing department has some purchase specifications; the production group, some process instructions; the inspection section, some testing procedures; the accounting office, some paper routines; the sales department, some product catalogues. Every one of these and hundreds more, in even the smallest of companies, are standards in every sense of the word. The program begins with an analysis and organization of these existing standards.

Of all these opportunities for the standardization effort, the best by far for a given company is the place where it is needed. A company seldom enters into standardization deliberately simply because it is a sound principle of management. Standards work can always be traced to a need for which standardization was the answer. The purchasing department may discover an increasing raw-material inventory of special items in small lots. The manufacturing division opens a new plant a thousand miles away from home and finds that process techniques are stored in the heads of the employees at home. The sales department is saddled with a number of slow movers. The vendors are changing specifications until the engineers are swallowed up in

* From O. F. Vea, "What Are the Reasons for Standardizing Electric Motors?," *Electrical Manufacturing*, August 1945, 108.

confusion. Every one of these is a problem to the departments concerned but also is an opportunity for standardization. Once the need has been identified, standardization can be of service.

A great help in starting standardization will be found outside the company. Visits to other companies active in standards work, not necessarily within a given industry, will always inspire ideas and opportunities. The work already done within an industry by other organizations, such as the trade association, technical societies, government groups, and the American Standards Association, should be compiled early in the program. The experience of others is always valuable.

4.4 THE STANDARDS ENGINEER

The qualities of an effective standards engineer, based on what he has to do, indicate that he must be: (1) particularly strong in the ability to handle human relations problems, (2) a good engineer, versed in the technical and productive problems of his company, and (3) an able administrator, capable of making competent business decisions.

4.4.1 Qualifications of a standards engineer.

A. Human Relations Skills

1. An abundant feeling for and understanding of people as individuals and in groups.
2. A keen sensitivity to and appreciation of the attitudes of people.
3. An ability to cope patiently with the common human characteristics of resistance to change and resentment of criticism.
4. A capacity to alleviate conflicting views and opinions in a forthright manner.
5. Consummate skill in obtaining agreeable cooperation from divergent individuals and groups.
6. A natural quality for doing and saying the right thing at the right time.

B. Technical Knowledge

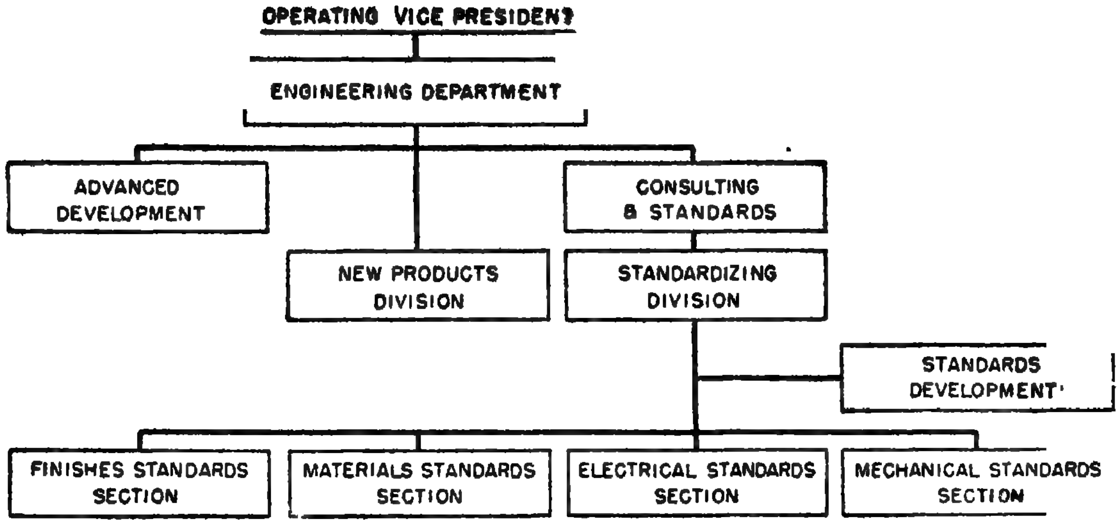
1. A well-rounded understanding of the fields of engineering basic to the company's operations.
2. A working knowledge of the specific technical problems of the company.
3. An extensive familiarity with the equipment and processes used in the company.
4. A practical skill in basic engineering terms, techniques, and troubles common to the industry.

C. Business Experience

1. A general understanding of the relationships of all phases of the company.
2. A particular interest in the practices and operations of other companies in the industry.
3. An extensive knowledge of the operations of individual departments in the company—*viz.* purchasing, production engineering, manufacturing, and industrial engineering.
4. A working knowledge of other departments in the company—*viz.* sales, accounting and finance, design, research and development.
5. A developed ability based on sufficient service in the company to make sound business decisions.
6. A well-rounded capacity to accept responsibility, to display initiative, and to temper authority.

4.5 ORGANIZATIONAL POSITION

The decision to start a program of standardization should never be hampered by a fear of where to fit the standards engineer into the organization. On the basis of the specifications set down for this individual, he will probably be working in the company. The new standardization program should have a small beginning; the selected individual should probably be permitted to carry on a portion of his regular work at the same time as he works into standardization. He should have relative freedom in his program and should seek his own



Courtesy of RCA.

FIG. 9.3 STANDARDS ORGANIZATION—STANDARDS ACTIVITY ASSIGNED TO THE ENGINEERING DEPARTMENT.

level in the organization. As the program grows and assumes increasing stature in the company, the problem of where to place the activity will disappear, for the answer will be self-evident.

Obviously, the scope of the program is limited in time by its organizational assignment. The standards engineer who reports to the chief production engineer will never find opportunity to carry out standards work in the sales department. Consequently, the standards engineer, from the beginning, should be encouraged to cut across organizational lines somewhat to make his program company-wide and not departmentalized. In a relatively short time, the universality of the standards effort should be apparent and its worth to the company as a whole completely clear. Thus, the standards engineer, if he is not in a high place in the organization, should in time certainly report to a high place (see Fig. 9.3).

4.6 METHOD OF OPERATION

The standards engineer works with problems that have a mutuality of interest and a complication of detail that force him to use several means of accomplishment. There will be, on the one hand, some pure routine activity vital to his program but involving decisions that rest exclusively with him. On the other hand, there will be decisions involving expenditures of money, obsolescence of inventory, scrapping of equipment, change of procedures, and sundry eddy effects throughout the company that by their nature no one man could engineer or install. These two opposite extremes of his activity naturally suggest two opposed methods of operating the standards program—the individual or expert approach versus the committee or participation approach. Making contacts with other companies and groups that will help him in his program, and collecting standards peculiar to his industry, he can do himself. Converting his company over to the new standard screw threads or simplifying and standardizing the product line, however, require complete coordination and control, full understanding and cooperation.

4.6.1 Committee approach. Some companies use the committee technique exclusively, with marked success. These committees range in responsibility all the way from policy-making down to working groups that prepare standards. There is much to be said for the committee,

since it serves several functions at once—it provides participation, promotes understanding, establishes agreement, and assures acceptance of the standards program. In a company that has the manpower and has highly developed and efficient committee-management relationships in its makeup, it is only natural that standardization should receive the same treatment as other activities.

Other companies who have tried to use the committee method have found it wanting. On the whole, committees are difficult to manage, particularly if they are expected to be productive. In those companies that have tried and failed, the problem always seems to be that of getting things done. The committee members were men already burdened with their own departmental duties and they reacted to standardization as another interference with their primary responsibilities. Many companies that have experienced this frustration are dead-set against committees. Others have lost interest in standardization or have at least set up barriers to its extension. Sometimes the program is simply handed to the standards engineer, who is expected to go it alone.

4.6.2 Expert approach. The standards engineer on his own is helpless. The very definition of standardization implies and demands that others be involved. Yet in too many companies the standards engineer is fighting time and tide trying with all his might to put this standard in here and argue that one in there. He meets with limited success. He is the expert and is treated as such by everyone—the know-it-all a long way from home. Yet once the way has been cleared, he moves quickly to action and results.

4.6.3 Combined approach. For the average company, the goal is to capture the swift movement of the lone man and the slow deliberation of the working committee. The decision of how much of each method the standards engineer should use depends primarily on what is to be accomplished and on the human relations problems involved. These decisions should be incorporated in his duties and responsibilities.

4.6.4 Duties and responsibilities of the standards engineer.

1. The standards engineer is charged with the total responsibility for the standards program, subject only to:

a. Higher authority on matters of policy, expenditure, and scope.

b. Company divisions on matters of content, use, and revision.

2. The higher authority will be a formal committee on standardization policy composed of top executives.

3. The company divisions may be one or more of the sections of the enterprise that are expected to comply with the standard. Their compliance is to be contingent upon their acceptance and they may reject a standard for cause.

4. The standards engineer will establish a program of activity for the company for a given period of time and submit it to higher authority for review, change, and comment.

5. The standards engineer will break down his program into projects by company interests and will have freedom to add or delete projects within the scope of the program approved by higher authority.

6. The standards engineer will do all preliminary work on each project:

a. Gather facts pertinent to the project both inside and outside the company.

b. Make a tentative decision on the content of the proposed standard.

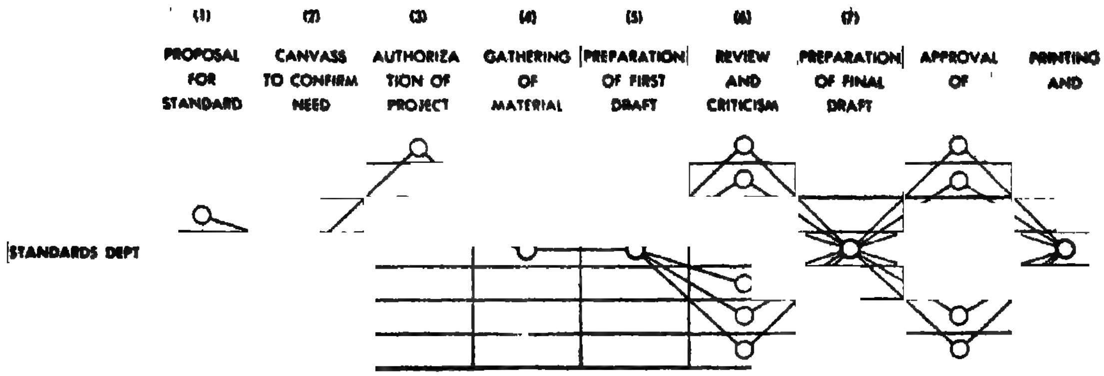
c. Obtain opinions and data supporting and refuting his proposal both inside and outside the company.

d. Sponsor research, investigation, or tests to establish the validity of his proposal.

e. Make such changes or corrections as may be deemed necessary.

7. The standards engineer will submit his proposed standard to all divisions of the company concerned for their approval and acceptance. Depending upon the scope of the standard, he may:

a. Submit it to each division head for his initials.



From L. M. Dalcher, "Administrative Standards in Business & Industry," *Standardization*, January, 1952.

FIG. 9.4 NINE STEPS TO A STANDARD—THE PROCEDURE FOLLOWED BY ONE COMPANY IN ITS STANDARDS DEVELOPMENT.

b. Submit it to a committee of representatives of these divisions for their approval.

8. The standards engineer will revise any proposed standard not approved or any existing standard rejected by any division concerned with its provisions until it is approved.

9. The standards engineer will keep such records, minutes, or data in connection with each standard as will be required to maintain a complete history of the standard.

10. The standards engineer will be responsible for the publication, binding, and distribution of accepted standards.

11. The standards engineer will be responsible for active participation in the standardization work of trade association, professional group, technical society, and national association.

These duties and responsibilities should not be accepted in detail by any company as here presented; they merely reflect good general practice. A specific company should establish its own method of operation. For example, one company has established nine steps in the production of a standard that suits their particular situation and that varies markedly from the above (see Fig. 9.4).

4.7 AREAS OF OPERATION

The principles of standardization may be applied to every phase of a business. As a matter of fact, however, standards engineers concentrate on those areas that combine both need and return.

4.7.1 Materials. Almost every company has done standardization work in connection with materials. These material standards are incorporated in "specifications" which are used not only by purchasing and by inventory control but by manufacturing and by design engineering. The specification generally indicates the use of the material and covers a variety of characteristics, such as chemical, electrical, and physical properties, and usually test and rejection procedures. The basic principle is that at least all properties that are critical will be specified. The effect of these standard specifications is to provide uniformity and agreement, as between vendor and purchaser (see Fig. 9.5). Within the company they provide, for receiving, an exact understanding of acceptable material, and, for purchasing, the possibility of alternate suppliers and quantity buying. The greatest advantage is the mutual understanding that results from a specification of the materials in all their particulars, with complete agreement on the

PURCHASING SPECIFICATION

RADIO CORPORATION OF AMERICA
RCA VICTOR DIVISION DIVISION STANDARDIZING CAMDEN, N. J.

100-1-24
PAGE - 1 OF 1
DATE - MAR. 15, 1950

SUBJECT PS-24 BLUED SPRING STEEL STRIP

1. Scope - These specifications and methods of test apply to hardened and blue tempered spring steel strip for use in the manufacture of high quality steel springs.

2. Composition - The material shall conform to the following requirements as to chemical composition:

Element	Percent
Carbon	0.85 to 1.05
Manganese	0.55 max.
Silicon	0.20 max.
Sulfur	0.045 max.
Phosphorus	0.045 max.

3. Temper - The material shall conform to the following requirements as to temper:

(a) Material over 0.020 inch in thickness shall be tested for hardness only. The hardness shall be 66 to 70, inclusive, Rockwell 30N Scale.

(b) Material 0.020 inch and under in thickness shall be tested for bending properties only. Strip of any width shall be bent 180 degrees between the jaws of a vise or testing machine, around pins of the diameters specified in Table I, in accordance with Figure I. The center line of the pin shall be approximately one inch from the outside of the bend.

The material shall either fracture transversely or remain intact in accordance with Table I. When a break occurs, it shall approximate a straight line perpendicular to the longitudinal axis of the test strip.

4. Dimensions - Dimensions shall be as specified on Drawing or Purchase Order, in accordance with the tolerances listed below unless otherwise specified.

Nominal Thickness, In.	Tolerance Plus or Minus
Up to .020, incl.	.0005
Over .020 to .040, incl.	.001
Over .040	.002

Width Plus or minus .005 inch

Strips shall be free from transverse bow, and the lateral bow or camber shall not exceed 3/8-inch in eight feet.

5. Form and Finish - Unless otherwise specified, material shall be supplied in coils of approximately equal length, in accordance with the usual commercial practice. The finish shall be the polished and blued grade.

The steel shall be uniform, clean, blue and smooth. It shall be free from rust, dirt, pits, seams, spots, cracks, slivers and other imperfections, in accordance with good commercial practice.

Edges shall be free from burrs, unless the order specifies that slit edges are acceptable.

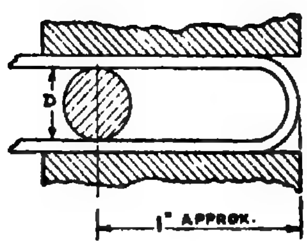
6. Packing and Marking - Material shall be packed in such manner as to protect it from damage during transit or storage.

Each bundle or shipping unit shall be suitably marked or tagged with this Purchasing Specification number, the thickness, width, length and net weight of material contained; the Purchase Order number and the name of the supplier.

TABLE I
Bend Test Requirements

Thickness, Inch	Diameter of Pin (D), In.	
	Without Fracture	With Fracture
Up to .0015	.062	.010
Over .0015 to .003, incl.	.093	.035
Over .003 to .006, incl.	.156	.062
Over .006 to .009, incl.	.218	.093
Over .009 to .012, incl.	.312	.140
Over .012 to .015, incl.	.375	.187
Over .015 to .020, incl.	.438	.218

Figure I
Bend Test



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Courtesy of RCA.

FIG. 9.5 STANDARD PURCHASING SPECIFICATION—AN EXAMPLE OF A STANDARD THAT PROMOTES UNDERSTANDING FOR MANY BOTH IN AND OUTSIDE THE COMPANY.

TABLE 9.4 STANDARD MACHINE PARTS LIST—ONE PAGE OF THE INDEX OF SELECTED PARTS STANDARDIZED FOR COMPANY USE*

FASTENING DEVICES
- C1 Bolts and screws
  - C1.2 Screw and washer assembly
  - C1A Alloy steel
  - C1B Brass
  - C1C Medium carbon steel
  - C1D Chrome stainless steel
  - C1E Bronze
  - C1F Chrome-nickel stainless steel
  - C1G Galvanized
  - C1H Aluminum
  - C1L Low carbon steel
- C2 Nuts
  - C2.1 Sheet metal
  - C2B Brass
  - C2D Chrome stainless steel
  - C2E Bronze
  - C2F Chrome-nickel stainless steel
  - C2G Galvanized
  - C2H Aluminum
  - C2L Low carbon steel
- C3 Rivets
  - C3.1 Eyelets
  - C3B Brass
  - C3F Chrome-nickel stainless steel
  - C3H Aluminum alloy
  - C3K Copper
  - C3L Low carbon steel
  - C3M Copper-nickel alloy
  - C3Y Miscellaneous
- C4 Washers
  - C4A Chrome-nickel stainless steel
  - C4B Copper alloy
  - C4L Low carbon steel
- C5 Pins
  - C5.1 Grooved straight
  - C5.2 Spring dowel
  - C5.3 Drive
    Page 1 threaded dowel pins K-5903495
  - C5A Taper, dowel, cotter
- C9 Miscellaneous
  - C9.1 Spring retaining rings, precision
  - C9.2 Spring retaining rings, square or round

CURRENT-CARRYING DEVICES
- C10 Contacts
  - C10A Contact tips
- C11 Brushes
  - C11A Carbon brushes
- C12 Connectors
  - C12.1 Brazed connectors
  - C12.10 Power connectors
  - C12.11 Power connectors
  - C12.12 Power connectors
  - C12.13 Power connectors
  - C12.14 Power connectors
  - C12.15 Power connectors
  - C12.16 Power connectors
  - C12.17 Power connectors
  - C12.20 Screw pressure—electrical
  - C12.21 Screw pressure—electrical
  - C12.22 Screw pressure—electrical
- C13.0 Terminal boards

BEARING DEVICES
- C20 Ball bearings
- C21 Roller bearings
- C22 Sleeve bearings and bushings
  - C22A Sintered
  - C22B Cast
  - C22C Wrought
    Page 1 oil rings
- C28 Lubricating fittings
- C29 Miscellaneous (meter jewels, etc.)
  - C29A Balls

MOTION TRANSMITTING DEVICES
- C30 Knobs, wheels, handles, etc.
- C31 Pulleys, sprockets, etc.
- C32 Gears
- C33 Springs
- C34 Keys
  - C34A Woodruff keys
- C39 Miscellaneous
  - C39A Bellows and assemblies

OTHER MECHANICAL PARTS
- C51 Gaskets
- C59 Nameplates
  - C59H Aluminum

PRODUCTS—SPECIALIZED PARTS
- C60 Motor, generator
  - C60A Capacitors
- C61 Turbine
  - C61A Piston rings
- C62 Transformer
- C63 Control
- C64 Switchgear
- C65 Meter and instrument
- C66 Electronic
  - C66A Leads and supports (Tubes)
  - C66B Cathodes (Tubes)
  - C66Y Miscellaneous
- C67 Protective equipment
- C68 Cable
- C69 Refrigerator
  - C69A Glass drip trays
  - C69B Flexible hose assembly
- C110 Inserts for plastics

* Courtesy General Electric.

meaning of terminology and on quantities and tolerances. Most companies have specifications for their raw materials, and many have extended this activity to their manufacturing, maintenance, and service supplies.

4.7.2 Parts. The next most extensive area in which standardization is practiced is in the field of parts, with particular emphasis on purchased parts (see Table 9.4). These specifications indicate the part by name and number and the various alternates of dimensions and shapes, including such other information as threads, finish, design data, and material. These standard-parts specifications are usually compiled in a standard-parts book, and range from ball-bearings to washers.

4.7.3 Engineering procedures and practices. The specification of materials and parts have naturally led to or have required standardization in many engineering procedures and practices. A standard numbering system might be developed for both parts and materials,

TABLE 9.5 STANDARD TEST METHOD—AN EXAMPLE OF A TESTING PROCEDURE STANDARDIZED AND ACCEPTED FOR MEASURING COMPLIANCE WITH SPECIFICATION*

G-E Test Method E1B39 governs the storage stability test for pressure-sensitive tapes, as follows:

E1B39A—50% relative humidity
E1B39B—90% relative humidity

APPARATUS:
Constant-temperature oven
Desiccator

TEST SAMPLE:
Roll of tape one inch wide and at least 10 yards long.

E1B39A—50% RELATIVE HUMIDITY

PROCEDURE:
Place the sample roll in a sealed desiccator over a solution which will give a relative humidity of 50 ± 5% at a temperature of 150 F. (Suggested solutions are sulfuric acid with specific gravity of 1.339, or a glycerine solution having a refractive index between 1.4440 and 1.4486.)
Store the sealed desiccator in an oven maintained at 150 ± 5 F for a period of 30 or 72 hours as specified.
After aging, allow the tape to cool for two hours at room temperature.
Examine the tape to determine the condition of the adhesive and backing.

REPORT:
The report should include the purchase order number, the manufacturer's name, the G-E designation, and a statement of whether or not the tape meets the requirements of the specification.

E1B39B—90% RELATIVE HUMIDITY

PROCEDURE:
Place the sample roll in a sealed desiccator over a solution which will give a relative humidity of 90 ± 1% at a temperature of 150 F. (Suggested solutions are sulfuric acid with specific gravity of 1.1368, or a glycerine solution having a refractive index between 1.3773 and 1.3905.)
Store the sealed desiccator in an oven maintained at 150 ± 2 F for a period of six days.
After aging, allow the tape to cool for two hours at room temperature.
Examine the tape to determine the condition of the adhesive and backing.

REPORT:
The report should include the purchase order number, the manufacturer's name, the G-E designation and a statement of whether or not the tape meets the requirements of the specification.

* Courtesy General Electric.

and later extended to tools, jigs, fixtures, and equipment of all kinds—not only in the productive areas, but in the service areas as well. A list of standard abbreviations, symbols, and terminology might be prepared, and from this will come the need for standard drafting procedures, including paper, lettering, and detailing. A further natural development would be the establishment of standard test methods (see Table 9.5). These test methods, including equipment and procedures, would be designed to assure the company that the supplier was complying with the standard material and part specifications. Many companies have gone a step further into the area of engineering design, including such items as limits, fits, tolerances, roughness, finishes, gaging, and similar design and mechanical data.

4.7.4 Manufacturing processes. Many companies have done standardization work in what might be called manufacturing processes and methods. These standards are in the areas of tool and equipment standards, including jigs and fixtures, and of operational standards, such as welding, heat treating, hardening, dehydrating, painting, cleaning, carbonizing, and other technical procedures (see Table 9.6). These manufacturing standards are particularly evident in the mechanical industry, but are not restricted to it.

4.7.5 Excluded areas. There are some standards closely allied to manufacturing that by custom are not considered areas

TABLE 9.6 STANDARD MANUFACTURING PROCESS—WRITTEN OPERATIONAL METHODS ASSURE UNDERSTANDING AND ENCOURAGE COMPLIANCE*

G-E Manufacturing Process P4C5 covers the procedure for electrolytic alkali cleaning of ferrous materials.

MATERIALS AND EQUIPMENT:

Electrolytic cleaning tank

Cleaning bath (1)

Alkaline cleaner.............. 8-10 oz/gal

Water to make............... 1 gal

(1) Various proprietary cleaners such as Pennsalt or Clepo are available. Consult your laboratory for approved materials. Material substitutions with corresponding changes in concentrations should be made only with the approval of the laboratory.

SAFETY PRECAUTIONS:

Acid resisting rubber gloves, rubber aprons, tight fitting goggles or face shield must be worn.

If cleaning solution is spilled on the body, wash immediately with water.

If cleaning solution gets into eyes, a small stream of running water should be directed *gently under* the eyelids for several minutes before going to the dispensary.

An exhaust ventilation system with monel, acid resisting coated wood or galvanized iron ducts and scrubbed air is recommended.

PROCEDURE:

Surface preparation:

Preclean—Remove oil and dirt. Use G-E Manufacturing Process P4C2 (vapor degreasing) or/and G-E Process P4C4 (Emulsion cleaning).

Electroclean—Immerse in electrolytic cleaning tank, making the parts cathodic for 90 seconds and then anodic for 30 seconds. The electrolytic cleaning bath operates at a temperature of 200 F with a current density of 50-60 amps/sq ft.

Rinse—Rinse thoroughly in running cold water.

Dry—If plating operations do not follow immediately, dip in hot water and dry by suitable means such as filtered air blast.

* Courtesy General Electric.

TABLE 9.7 STANDARDS INDEX—AN EXAMPLE OF THE POSSIBLE SCOPE OF THE STANDARDS ACTIVITY IN A COMPANY*

SECTION	SUBJECT
AD	ADMINISTRATION
AU	AUDITING & ACCOUNTING
EN	ENGINEERING
IN	INSPECTION
MS	MATERIALS & SUPPLIES
PE	PERSONNEL
PN	PRODUCTION
SA	SAFETY
SP	STANDARD PARTS
TE	TOOLS & EQUIPMENT

* Courtesy Fairbanks, Morse & Co.

of activity for the standards department. These are related to the activities of the industrial engineering or methods department. This group standardizes within its own sphere of influence, developing standard time data, techniques, allowances, and production rates, and standard charts, three-dimensional models, templates, and layouts, and standard reports, practices, and procedures as a separate and distinct set of standards (see Sections 5, 6, 8, 10, 11, and 14). To a lesser extent, certain managerial standards are kept apart from the standards group. These include standard practice instructions that consist of written policy and procedure in such fields as organization, accounting, employment, branch-plant operation, and other aspects of control in the operation of the enterprise. In like manner, product standards may not be handled by the standaids group, together with such items as catalogues, installation and servicing instructions, replacement parts lists, and operating instructions. Safety standards likewise fall into this disputed category. Whether these, all or in part, should be within the jurisdiction of the standards group is a matter of plant practice and standards policy (see Table 9.7).

4.8 STANDARDIZATION TECHNIQUES

Even though standardization is generally considered to be an engineering activity, very few technical methods of attack on the problems of standardization have been developed.

4.8.1 Simplification. The easiest step to take in standardization is to use the technique known as simplification. This is the process of reducing variety by elimination. A company that makes 260 types of washers decides, by reviewing the cost and sales situation, not to make 150 of them. Another company, which uses 26 different types of lubricants, analyzes its needs and finds that 10 will satisfy its requirements. This process is as simple as these examples suggest; the prime problem is to obtain some agreement on what will be eliminated (see Figs. 9.6 and 9.7). This work is the application on a company level of the principles and practices described previously under the Commodity Standards Divi-

From "Engineering Standards at IBM," *Standardization*, December, 1950.

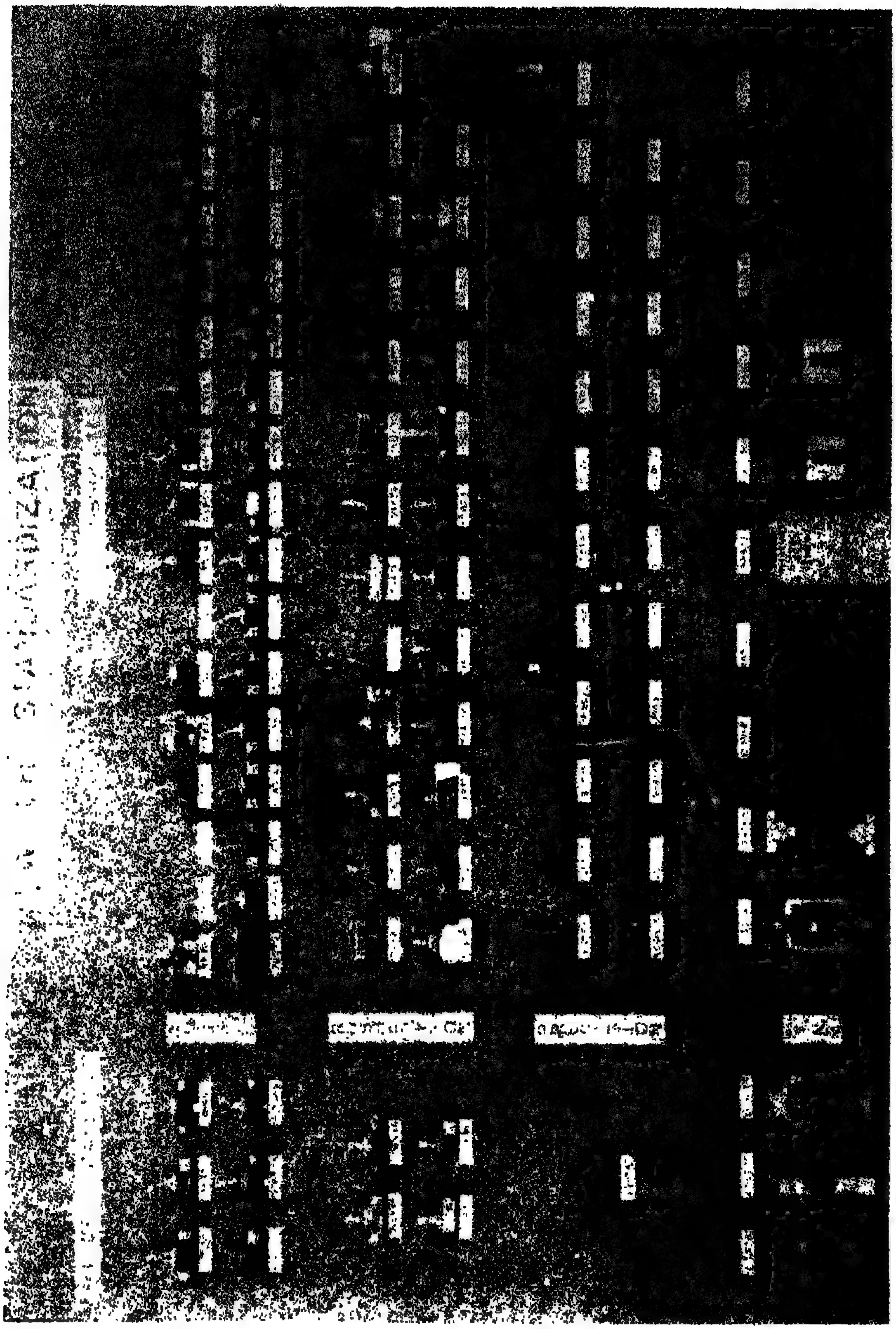
FIG. 9.6 SIMPLIFICATION IN MANUFACTURING—FOUR STANDARD KNURLS SATISFACTORILY REPLACED A LARGE NUMBER OF NONSTANDARD KNURLS.

sion of the Department of Commerce that resulted in Simplified Practice Recommendations (Art. 2.4.3.3).

4.8.2 Deliberate decision. Simplification consists of a review of current variety followed by a decision on what is acceptable and therefore standardized. This technique presupposes that the present variety has been the result of considered engineering thought and deliberate selection. Such is usually not the case. The result is, therefore, standardization by compromise. The more desirable engineering investigation to determine the needs of the situation has not been made. There is no technique that applies to this final accomplishment of standardization, referred to as "deliberate decision," except the straightforward engineering approach coupled with patient participation (see Fig. 9.8).

4.8.3 Preferred numbers. There is one tool of standardization—preferred numbers—that supports deliberate decision. These are numbers that have been selected and standardized in the form of a series of geometrical relationships, so that the relationship of the value of one number to the next is always the same. Thus, in the five series from 10 to 100 there are five numbers that are approximately 60 per cent apart from each other. These numbers (see Table 9.8) have been adopted for use by designers in preference to arbitrary numbers in order to create uniformity and consequent interchangeability. They are applied to sizes, ratings, or characteristics, such as diameters, lengths, areas, volumes, weights, and capacities.

4.8.4 Numbering systems. Standards engineers have developed administrative techniques that support and direct their programs. The most common of these is the standard numbering system. The type, form, and content of the system varies from company to company. The simplest system is to number from one on up; or the system may be more complex, employing combinations of letters and numbers (see Fig. 9.9). In any case, the purpose is to designate the material, part, process, procedure, or other standard to be specified. Through the numbering system, the standards group can extend its activities legitimately, for nonstandard items, being unnumbered, are plainly visible. In like manner, the



Courtesy of IBM.

FIG. 9.7 SIMPLIFICATION IN PURCHASING—REDUCTION IN PURCHASED PARTS MEANS SIGNIFICANT SAVINGS IN THE PRODUCT.

INTERNATIONAL HARVESTER MANUFACTURING STANDARDS

F-7

STANDARD DIAMOND DRESSING TOOLS

1. PURPOSE & SCOPE

To reduce the many sizes and styles of diamond dressing tools and to establish maximum sizes of diamonds, the data shown below is adopted as a company standard for use by manufacturing works in the dressing and truing of grinding wheels. Included are four standard styles of tools and the maximum size of diamond for each.

The four standard styles of tools are:

A-1 Single point, straight shank, general purpose.

B-1 Single point, head type, general purpose.

C-1 Cluster tool, head type, general purpose.

D-1 Single point, head type, Heald and general purpose.

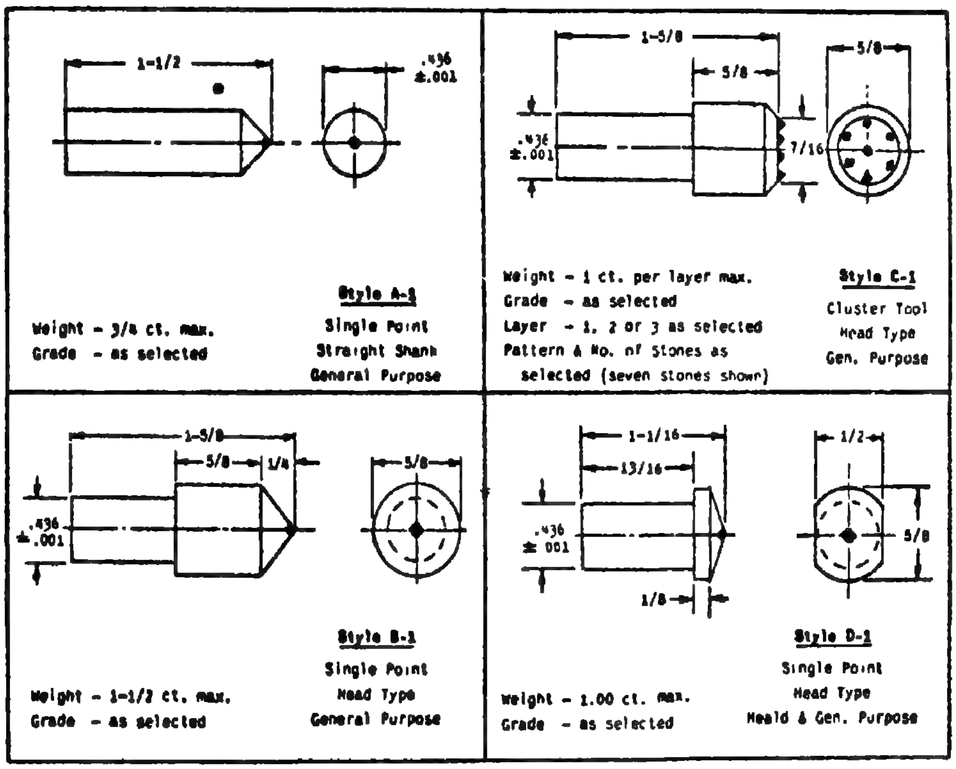
This data approved March, 1960 by the Mechanical Engineers Committee.

2. MAIN TEXT

For identification purposes, individual tools of each style should be stamped with a serial number and with the carat weight.

Details of the four standard dressing tools are shown in the following sketches.

STANDARD DIAMOND DRESSING TOOLS



March, 1960 1 Page

Courtesy of International Harvester.

FIG. 9.8 SIMPLIFICATION AND DELIBERATE DECISION —NOT ONLY WERE THE TOOLS REDUCED FROM 125 TO 4, BUT THEY WERE DESIGNED FOR THE JOB.

TABLE 9.8 BASIC PREFERRED NUMBERS—THE 5, 10, 20 AND 40 DECIMAL SERIES (10 TO 100)*

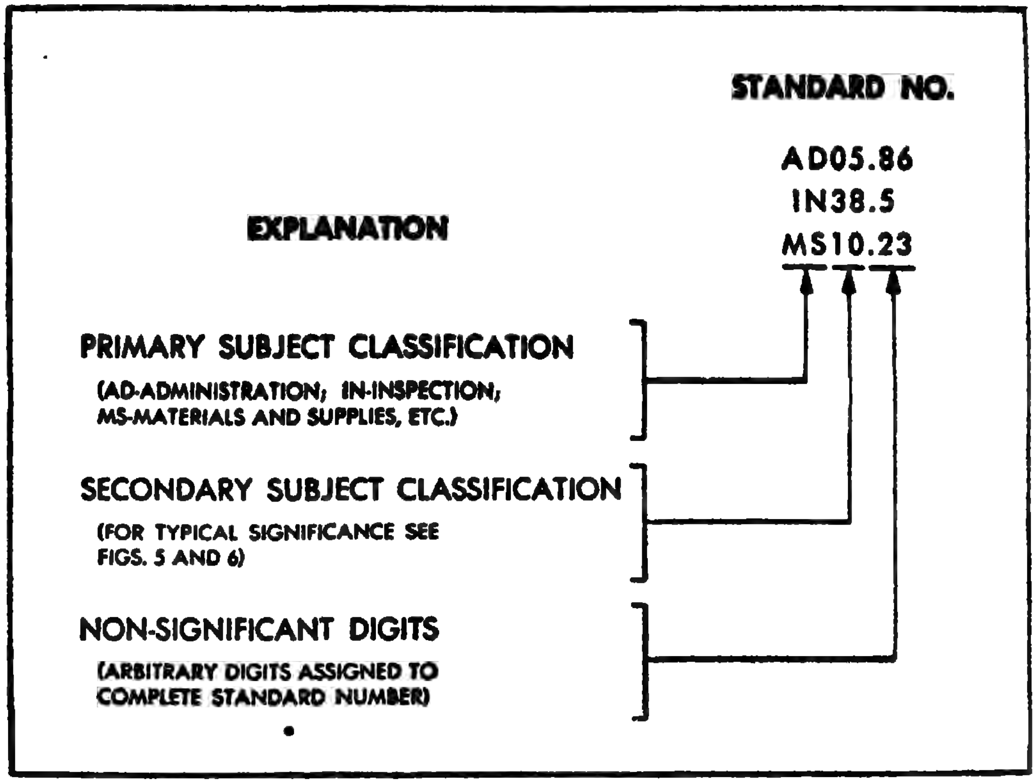
5-Series (60% Steps)	10-Series (25% Steps)	20-Series (12% Steps)	40-Series (6% Steps)
10	10	10	10
			10.6
		11.2	11.2
			11.8
	12.5	12.5	12.5
			13.2
		14	14
			15
16	16	16	16
			17
		18	18
			19
	20	20	20
			21.2
		22.4	22.4
			23.6
25	25	25	25
			26.5
		28	28
			30
	31.5	31.5	31.5
			33.5
		35.5	35.5
			37.5
40	40	40	40
			42.5
		45	45
			47.5
	50	50	50
			53
		56	56
			60
63	63	63	63
			67
		71	71
			75
	80	80	80
			85
		90	90
			95

Preferred Numbers below 10 are formed by dividing the numbers between 10 and 100 by 10, 100, etc.

Preferred Numbers above 100 are formed by multiplying the numbers between 10 and 100 by 10, 100, etc.

Percentage steps in headings are approximate averages.

* From *American Standard Preferred Numbers, Z17.1—1936 R 1951*, published by the American Standards Association.



Courtesy of Fairbanks, Morse & Co.

FIG. **9.9** STANDARD NUMBERING SYSTEM—THE METHOD ONE COMPANY EMPLOYS FOR ITS STANDARD NUMBERS.

group can control nonstandard practice in the company by requiring that a standard number be assigned to all materials, parts, and so forth.

4.8.5 Standard format. Unless detailed thought is given to the form and content of the prepared standard at the start, they present recurring problems. Most standards engineers follow the easiest course of being guided by examples from other companies or from other groups, like the ASA, and of accepting and incorporating the suggestions of their company executives. This means that experience gained in preparing standards tends to indicate necessary change in the form, content, wording, and presentation of the standard until one generally acceptable format, uniquely the company's, is developed.

Considerable help in developing a uniform format will be gained by consulting ASA's "Style Manual for American Standards," and by using its recommendations as a guide toward more readable and understandable standards.

4.8.6 Printed standards. The next most consistent technique is the practice of putting standards in writing. The advantage of written standards in promoting understanding and compliance is evident. For the standards group, the decision on what the form and content of the standard should be requires a complete survey of the standard before its publication; in many cases, problems of agreement are introduced on control data that have never been considered by the company before. Thus, in the specification of a cleaning solution, prior to standardization, the brand name might have been the critical characteristic, whereas, after standardization, the quality of carbon tetrachloride by weight in the solution might be the critical characteristic. Obtaining agreement from all parties concerned in regard to really critical information provides the standards

group with a broader base for its activities. The printed standards, collated and assembled, generally in loose-leaf binders, constitute for every company the heart of the standards program. These standards manuals, as they are called, are kept up to date by the standards department and are distributed to all interested sections of the company.

4.8.7 Standards control. Through standards manuals, the department gains standards control over company practices, such as in design, manufacturing, and purchasing. In turn, they furnish operating personnel with an opportunity to indicate additional areas for standardization work in the form of recommended standards projects. In exercising control, probably the best practice is to require that the standards group be informed whenever a nonstandard is employed. The purpose of this requirement is not to require compliance but to indicate the need for investigation of nonstandard practice. Thus, the purchasing department might be required to send a copy of a requisition for a nonstandard material to the standards department for the latter's information. Frequent use of nonstandard practice certainly would indicate the need for review of the situation and for action on the part of the standards engineer.

4.8.8 Outside contacts. The standards group should, and usually does, maintain an active liaison with other individuals, organizations, or groups that do standardization work. It is desirable that the company join the American Standards Association and that the standards engineer be active in the standardization work of the ASA, of trade associations, and of technical societies. In addition, the standards engineer should keep in close touch with the standards and specifications work of government agencies, particularly with respect to his own industry. It is good standardization practice to permit the standards promulgated by the ASA, trade associations, technical societies, and the government to form the basis for standards approved and accepted within the company.

4.9 STANDARDS PROGRAM PROBLEMS

Here are some of the perplexing situations that are likely to arise in any standardization program:

1. Gaining and maintaining top-management's active, rather than passive, support.
2. Deciding extent and limits of acceptance of standards throughout the company.
3. Arbitrating requests for use of nonstandard conditions.
4. Timing the promulgation and adoption of standards.
5. Exploiting the opportunity to extend the scope and activity of the standards group.
6. Developing coordination in the total standards effort.
7. Resisting the pressure of time and situation to formulate a standard before complete.
8. Determining the purpose and coverage of a proposed standard.
9. Deciding the method and extent of evaluation of the standards effort.

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Every practising standards engineer should have a copy of Paul W. Dickson's booklet, which is mainly an account of standardization programs in many leading companies. He should also subscribe to the monthly magazine published by the American Standards Association. Of the books listed, John Gaillard's can be considered the "Bible" of standardization since it is a comprehensive and detailed treatment of many facets of the subject.

Lawrence E. Doyle, Associate Professor of Mechanical Engineering at the University of Illinois, received his undergraduate training in Mechanical Engineering at Yale University. He received the B.S. degree in 1930 and immediately embarked on a career in industry.

He spent a number of years as Sales and Service Engineer with the Cincinnati Milling Machine Company and then transferred to the Allison Division of General Motors at Indianapolis. There he was Assistant Supervisor of Process and Tool Engineering. From 1943 to 1945 he was consultant to industry with N. E. Miller and Associates in Detroit.

He returned to university teaching in 1946 at the University of Illinois and embarked on a simultaneous program of graduate study. He received the M.E. degree from that University in 1950 and continued on in his capacity as associate professor of Mechanical Engineering.

Mr. Doyle is one of the leading authors on the subject of tool engineering and related subjects. He has written two textbooks, *Tool Engineering: Analysis and Procedure* and *Metal Machining* and a number of articles and papers.

Mr. Doyle is Co-chairman of the Professional Engineering Committee of the Chicago Chapter and Chairman of the National Professional Engineering Committee of the American Society of Tool Engineers. He is a director of the Illinois Engineering Council, a member of the Education Committee of that organization, and a member of the Legislative Committee of the Illinois Society of Professional Engineers. He is also a member of the American Society for Engineering Education, the American Society for Metals, and the National Society of Professional Engineers.

SECTION **10**

Tool Engineering

Lawrence E. Doyle

1. THE NATURE AND SCOPE OF TOOL ENGINEERING

1.1 DEFINITIONS

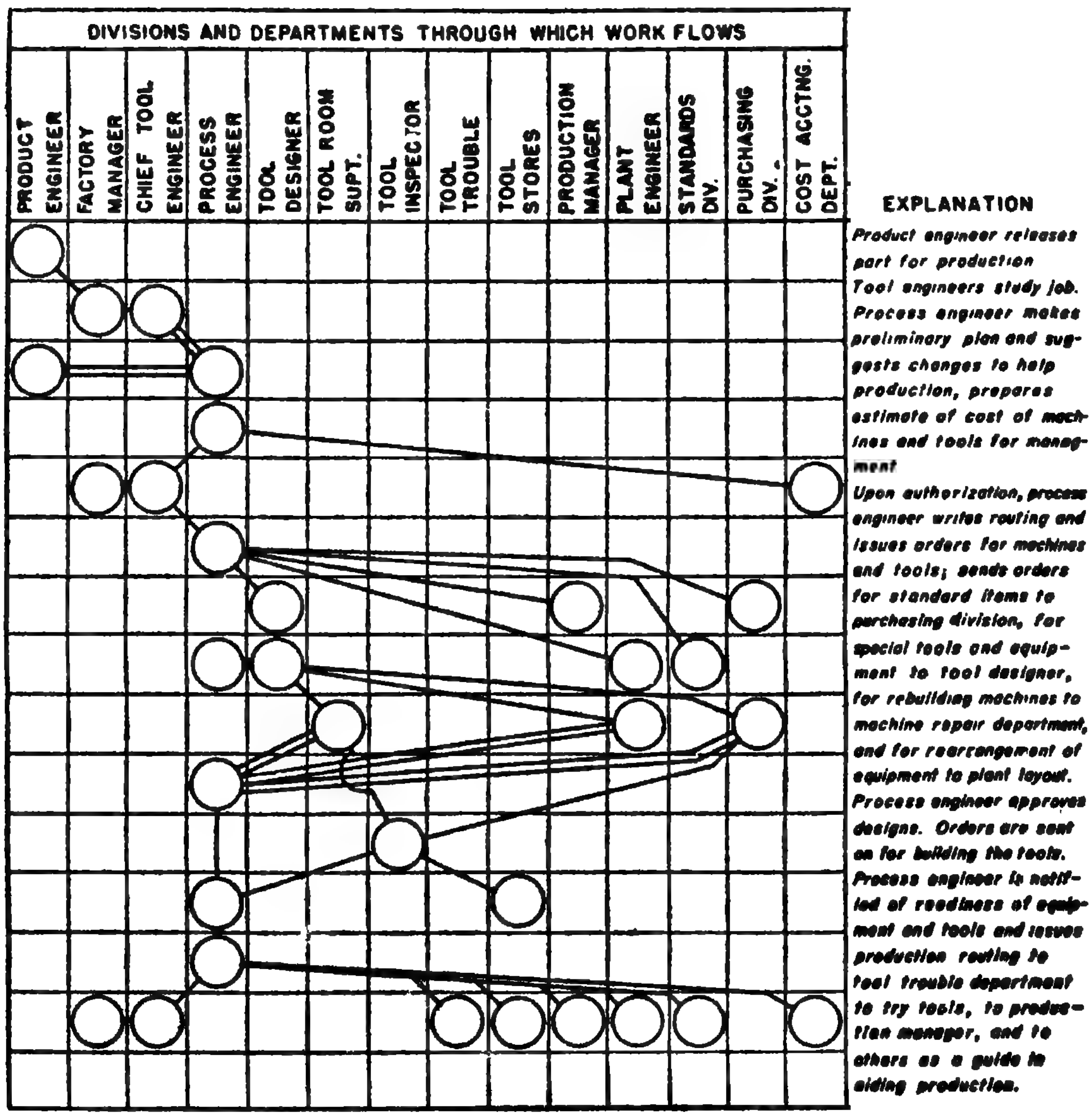
Tool engineering is concerned with planning the processes, supplying the tools, and coordinating the facilities for economical manufacturing. Thus, it contains two main activities: process planning and tool designing.

Process planning or *process engineering* consists of devising, selecting, and specifying processes, machines, tools, and other equipment to cut, form, and furbish materials, finish manufactured articles, and assemble products.

Tool designing or *tool design* involves the development and design of machinery, tools, and gages for production.

1.2 THE FUNCTION OF TOOL ENGINEERING IN AN INDUSTRIAL ORGANIZATION

Tool engineering is one of the staff functions that supply services and facilities to the productive core of an industrial organization. In that respect, tool engineering is like purchasing, accounting, and plant maintenance. In a small plant, the entire tool-engineering function may be performed by one person as part or all of his duties. In a



Lawrence E. Doyle, *Tool Engineering: Analysis and Procedure* (New York: Prentice-Hall, Inc., 1950), p. 6.

FIG. 10.1 AN OUTLINE OF PROCEDURE FOR TOOLING A PART FOR PRODUCTION.

large organization, the tool-engineering effort is divided among several departments under the direction of the chief tool engineer, also variously known as the master mechanic, production engineer, or manufacturing engineer, who reports to the top production manager. Typical tool-engineering departments are process engineering, tool design, tool making, tool inspection, tool trouble, and tool stores departments. An explanation is given in Fig. 10.1 of a typical procedure followed by such departments in preparing for production.

2. PROCESS PLANNING

2.1 THE PURPOSE OF PROCESS PLANNING

Process planning is done to determine and describe the best process for each job so that

(1) Specific requirements are set forth, for which equipment and tools can be selected or designed.

(2) The efforts of all engaged in preparing for production are coordinated.

(3) A guide is furnished to show the best way to use the facilities provided.

A process plan for a job represents the solution to a series of problems which require that means be found to

(1) Give a certain form, shape, composition, and other characteristics to a product.

(2) Hold specified tolerances in dimensions, surface quality, material properties, and so forth.

(3) Realize as high a rate of production at as low a cost as feasible, and produce when needed.

2.2 THE CONTENTS OF A PROCESS PLAN

Certain basic principles are applied in solving the problems of process planning. A process plan should contain those items that show how it proposes to resolve efficiently the problems at hand. The items to include in a process plan are:

(1) An identification of the purpose of the process. This calls for the name and number of the article to be produced, the quantity and lot sizes to be made, a description of the rough material, the model or assembly for which the unit is intended, the number of units in each assembly, the effective date of the project, the name of the planner, and the number of the order authorizing the project.

(2) A designation of the division of work, including a list of the operations making up the process, an enumeration of the operations to show their sequence, and designation of the place where each operation is performed.

(3) Specifications needed to make each operation conform to the principles of interchangeable manufacture and quality control. These items include the locating surfaces and clamping areas on the workpiece, dimensions, tolerances, geometric relationships, surface quality, and material properties.

(4) Specifications of the methods, machines, tools, and equipment to produce the required quantity and quality of product at the lowest cost. These include a description of what is to be done in each operation; the size, type, and kind of each machine and its location, accessories, and attachments; listing and identification of standard and special cutting and forming tools, fixtures, jigs, dies, gages, and so forth; and instructions for the proper setup and operation of the equipment, optimum speeds, feeds, and so on.

(5) Specifications of performance expected from each operation, in the form of the estimated or standard cycle time per piece and setup time per lot; the output expected in a certain length of time; and the capacity of the equipment.

2.3 HOW PROCESS PLANS ARE EXPRESSED

A process plan is a complete concept of a process. It is recorded and transmitted in a number of ways

to suit various conditions. Seldom does the paper work express the whole plan. In a small plant or where skilled workers may be relied upon to perform without detailed instructions, process plans may be recorded quite incompletely. In a large organization with a complex product and highly refined procedures, process plans may be recorded in minute detail.

A process-planning medium almost universally used is the *routing,* also known as *route sheet, process sheet, planning operation sheet,* and so forth, that lists and describes the operations of a process. One form of routing is shown in Fig. 10.2. Routings are written as briefly as possible to save time, and they commonly designate departments, machines, tools, etc., by numbers and symbols. A routing is used in many parts of a plant, and a number of copies are generally issued. All copies should contain the basic information, but some may

FIG. **10.2** ONE FORM OF ROUTE SHEET.

PLANNING OPERATION SHEET NON-CURRENT (X)

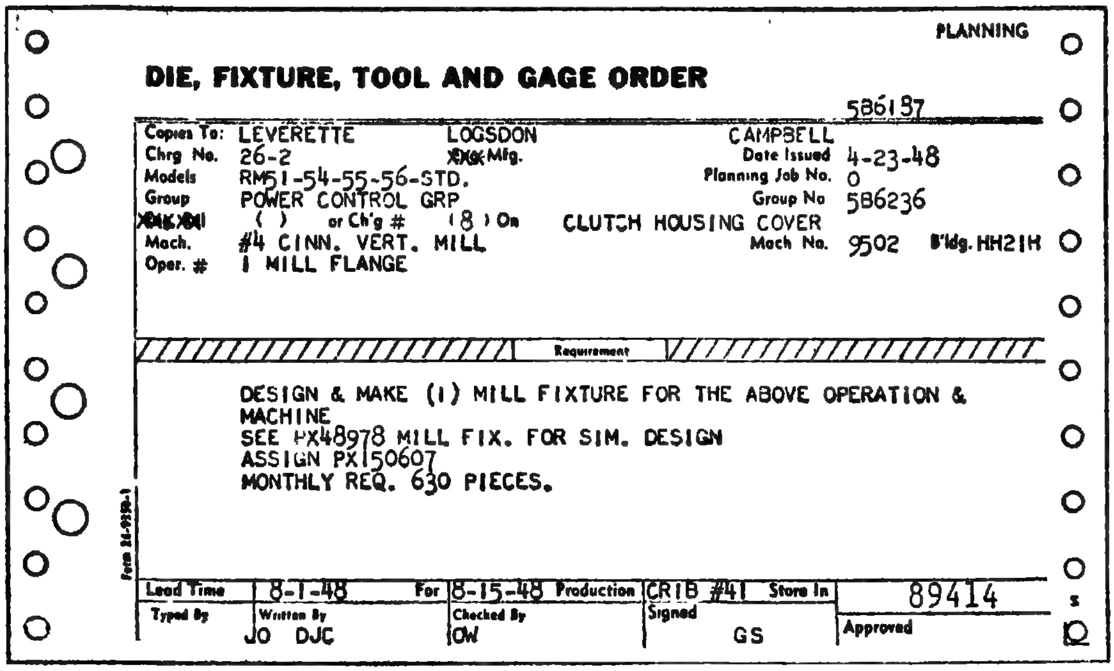
TRACT LOT 630 PART NO. 5B6187

EFFECTIVE DATE 8-1-48

OPER. NO	MACHINE LOC. CLASS	M NO	BASE TIME HRS PER SET UP	HRS PER PIECE	BURDEN HOURS	PERFORM HOURS	OPERATION
							Paint
1	HH21H M4V	9502	1.00	.2222 4.5	1.00 .2222	1.00 .2222	Mill Face (PX150607)
2	HH22H D22M	9484	2.70	.0759 13	2.70 .0769	2.70 .0769	Drill (16) 13/32, (6) 47/64,
							(4) 11/16 holes (PX48769)
3	HH22F D14R	9490	1.00	.0909 11	1.00 .0909	1.00 .0909	Drill & Ream (2) Dowel Holes and
							Drill (6) 11/32 & (2) 11/16 holes
							(PX48770)
4	HH22F D14R	9490	1.00	.2052 4.875	1.00 .2052	1.00 .2052	Drill, Bore & Ream (12) Large Holes (PX150608)
5	HH22F D14R	9490	.80	.1333 7.5	.80 .1333	.80 .1333	Drill & Tap Pipe Hole and Chamfer Large Holes (PX52712)
6	HH22F D14R	9490	.50	.066 15	.50 .0667	.50 .0667	Chamfer (6) 47/64 holes (PX53171)
7	HH22F D14R	9490	.50	.1053 9.5	.50 .1053	.50 .1053	Drill (6) Angle Oil Holes (PX150611)
8	HH23F X1W	4692	.20	.0555 18	.20 .0555	.20 .0555	Wash
							PARTS GRP NO

COMP PARTS 1A6804	MATERIAL C. T. #1E 19 Iron Casting				
	PART NAME Clutch Housing Cover				QTY PER PC.
	MACH. PREPARED DJC 4-22-48	BASE TIME EFT 4-22-48	QTY	MODEL	DELIVER TO
		MACH. RECORD			
	SUPERSEDES SHEET DATED 10-17-47	ISSUE NO.	ORDER DATE	SCHED LOT SIZE	SCHEDULE	QTY. STILL OR ORIG'S REC'D
	MASTER TYPED	DATE COMPLETED FOREMAN'S SIG	PART NO 5B6187			

Doyle, *Tool Engineering: Analysis and Procedure,* p. 254. Courtesy of the Caterpillar Tractor Co.



PLANNING

DIE, FIXTURE, TOOL AND GAGE ORDER

586137

Copies To: LEVERETTE LOGSDON CAMPBELL
Chrg No. 26-2 XXX Mfg. Date Issued 4-23-48
Models RM51-54-55-56-STD. Planning Job No. 0
Group POWER CONTROL GRP Group No 586236
XXXXX ( ) or Ch'g # (8) On CLUTCH HOUSING COVER
Mach. #4 CINN. VERT. MILL Mach No. 9502 B'ldg. HH21H
Oper. # 1 MILL FLANGE

Requirement

DESIGN & MAKE (1) MILL FIXTURE FOR THE ABOVE OPERATION & MACHINE
SEE PX48978 MILL FIX. FOR SIM. DESIGN
ASSIGN PX150607
MONTHLY REQ. 630 PIECES.

Lead Time	8-1-48	For 8-15-48 Production	CRIB #41 Store In	89414
Typed By	Written By JO DJC	Checked By OW	Signed GS	Approved

Doyle, *Tool Engineering: Analysis and Procedure*, p. 255. Courtesy of the Caterpillar Tractor Co.

FIG. **10.3** A TYPICAL TOOL ORDER.

have certain spaces reserved for, and contain information of value only to, their recipients.

A tool order, exemplified in Fig. 10.3, is a common supplement to the routing to convey specifications for designing or procuring a tool.

An operation instruction sheet, like the one in Fig. 10.4, describes an operation in more detail than is feasible on a route sheet. A sketch of the work to be done in the operation is customary on these sheets.

3. THE PROCEDURE OF PROCESS PLANNING

The problems met in planning a process can be solved most readily in a definite logical order. Some must be solved before others. The steps to be taken entail the following considerations.

3.1 THE REQUIREMENTS AND CONDITIONS OF THE PROCESS

Before any problem can be solved, its requirements and conditions must be defined. In process planning, what must be determined first are:

(1) The specifications of the finished product.

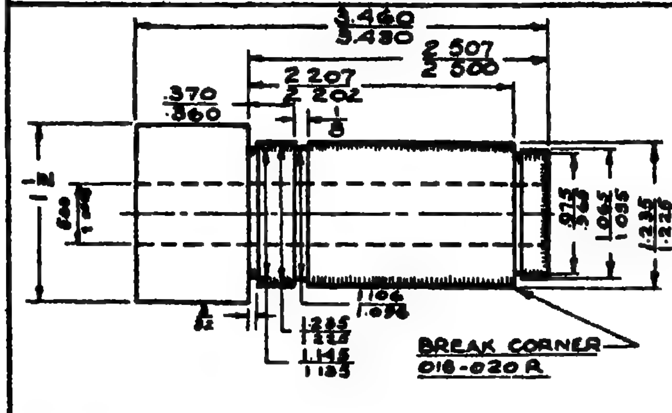
(2) The size, shape, and other properties of the raw material.

(3) The quantity or number of pieces of the product to be made and the date required for delivery.

The specifications for a mechanical device are found in part and assembly prints, an engineering release for production, a manufacturing order, and a list of parts or materials. These forms reach the tool engineer when a job is assigned to him in the course of events depicted in Fig. 10.1. Sometimes the design specifications do not state the quantity to be made or the form of raw material. An estimate of quantity may have to be obtained from the sales department or the management. The tool engineer may be required to study and choose from several possible forms of raw material.

The process engineer should make a mental or written list of every item in the specifications to obtain a full grasp of the project. The items include the surfaces to be finished, quality of finished surfaces, individual dimensions and tolerances, geometric relationships among

DEPT	PART # 476389-HOLDING COLLAR	OP NO. 10
OPER. OPERATION NO. 10 - SEE DRAWING		SEQ NO.
		GAGES



MACHINE HAND SCREW MACHINE

TOOLS		TOOLS	
W&S M1887	4-TOOL HOLDER	C-7312561-A1	1-TURNING TOOL
W&S M1373	2-TURNER	C-7312561-A1	1-TURNING TOOL
W&S M949	1-DRILL SOCKET	W&S M-874	1-STARTING DRILL
W&S M622	1-FLOATING TOOL HOLDER	STD	1-15/32 DRILL
W&S M1700	1-TOOL BLOCK	C 7312561-A3	1-BUSHING
W&S 461-100	1-MASTER COLLET	STD	1-½ ROSE REAMER
C-7312560-D	1-STOP	C-7312561-A6	1-NECKING TOOL

REMARKS
USE WD 4150 MOD - 1½ DIA BAR STOCK - APPROX 300
BRINELL
TURN ALL DIAMETERS EXCEPT 1½, GROOVES, DRILL & REAM
& CUT OFF & FACE SMALL END
STATION #1 - STOP BED TURRET
" #2 - TURN 1.235 DIA.
" #3 - TURN 1.065 DIA.
" #4 - STARTING DRILL
" #5 - DRILL 15/32 HOLE
" #6 - FACE FRONT END - SLIDE TURRET
" #7 - FINISH REAM - BED TURRET
" #8 - NECK 3 PLACES - REAR SLIDE
" #9 - CUT OFF - FRONT SLIDE
HAND FILE - BREAK CORNER .015-.020 R.

Halsey F. Owen, *Introduction to Tool Engineering* (New York: Prentice-Hall, Inc., 1948), p. 50.

FIG. **10.4** AN OPERATION INSTRUCTION SHEET.

surfaces, physical properties of materials, surface painting or plating, assemblies, and other refinements.

3.2 IMPROVEMENT OF THE SPECIFICATIONS

Mere recognition of the items of the specifications is not enough. A competent tool engineer always looks for ways to improve the specifications to make production easier and cheaper.

The tool engineer has a right to expect all specifications to be clear and explicit and to insist that they be corrected if confusing, ambiguous, or incomplete. Examples of faulty specifications are overlapping dimensions, omitted tolerances, or indefinite notations for surface-finish quality.

A capable process engineer is often able to suggest changes in the design of a product to benefit production because he is in close touch with the problems of production. Such suggestions

may range from a complete change to a minor alteration in the design of a part. The right to accept or reject changes belongs to the product designer who is responsible for the performance of the product. A few illustrations of typical changes are given in Fig. 10.5.

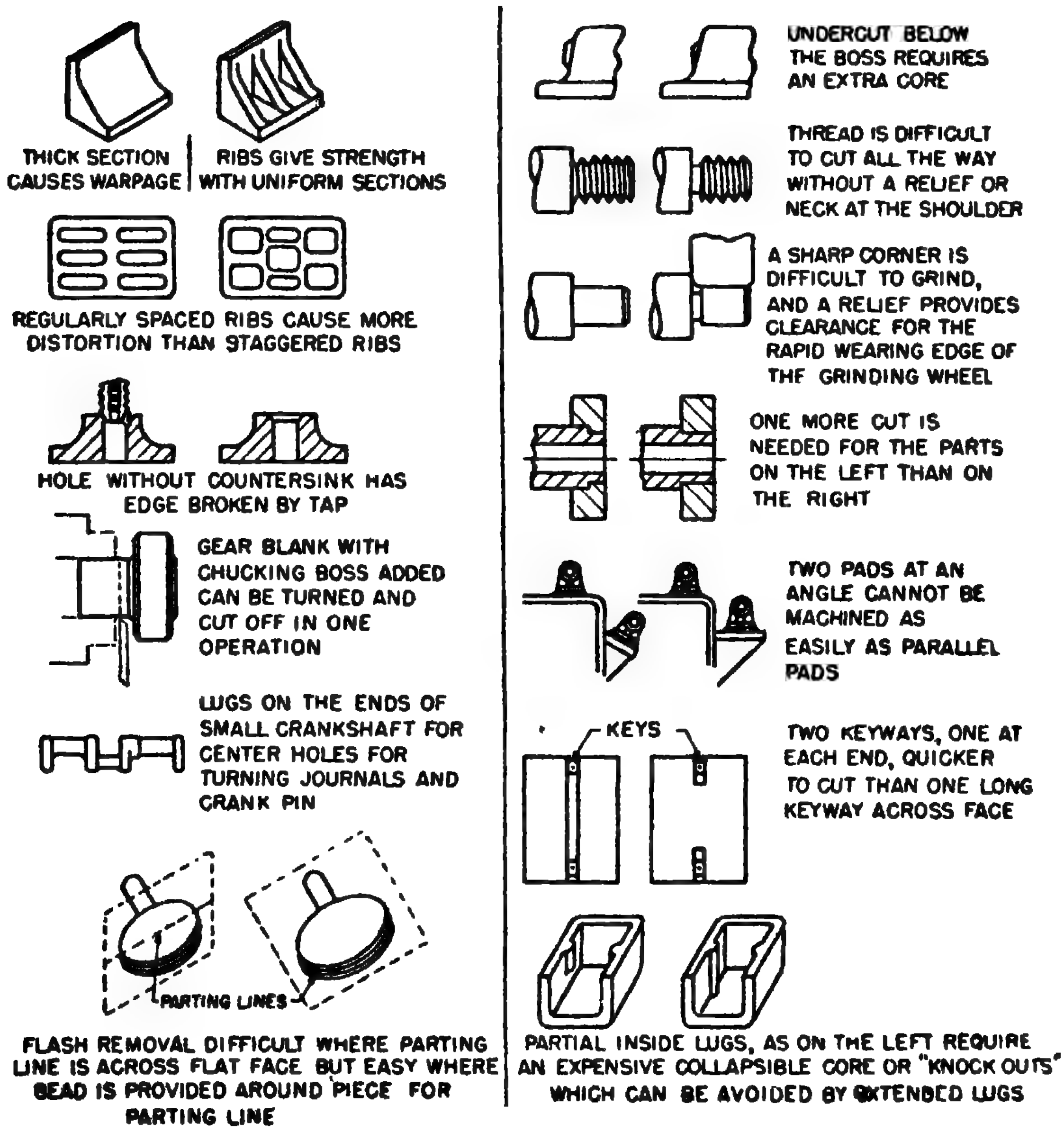
The following is a suggestive outline of important types of changes to promote economy in processing:

(1) Change in assemblies to reduce the number of parts needed (as by combining parts), or to simplify parts (as by enlarging tolerances).

(2) Additions to parts in the form of pads, ribs, fins, lugs, reliefs, etc., to control warpage, to reduce deflection, to add strength to resist processing forces, to aid in holding the workpiece (as by means of chucking rings), to aid in driving the workpiece, to aid in locating the workpiece, to prevent surface mutilation, to provide runout spaces for tools, and to provide foolproofing means.

(3) Changes in the shape, size, or material of a part to enable the part to be made by a more economical process, reduce tooling costs, decrease

FIG. 10.5 TYPICAL PRODUCT DESIGN CHANGES THAT HAVE RESULTED IN PRODUCTION ECONOMIES.



machining time, reduce the number of operations in a process, reduce material cost and waste, and aid in assembly.

3.3 PRINCIPLES OF DIMENSIONING

The dimensions of a part specify the positions and conditions of its surfaces. In general, surfaces may be classified as *functional surfaces*, which enter into the operation or location of the part in a mechanism; *clearance surfaces*, which provide continuity in the part but have no functional role; and *atmospheric surfaces*, which are not near other surfaces in the mechanism. Dimensions between functional surfaces have relatively small tolerances, dimensions to clearance surfaces have larger tolerances, and dimensions to atmospheric surfaces have the largest. Base lines for dimensions frequently coincide with functional surfaces. The tolerances on the dimensions of a part drawing are indicative of the relative importance of the surfaces to which the dimensions apply.

The cost of holding a tolerance on a dimension increases as the tolerance decreases, in the manner indicated by the curve *cd* of Fig. 10.6. The best service is obtained from a particular part when a small tolerance is held; then the value of the product is high. With a larger tolerance, some pieces fail too soon and the average quality of the product is lowered, as indicated by the curve *ab* of Fig. 10.6. The most economical tolerance for the dimension is T, which gives the largest difference between product value and cost. Obviously, a larger tolerance may be as wasteful as a smaller tolerance.

The factors affecting every dimension are like those depicted by the curves of Fig. 10.6, but they do not have the same values for each dimension. A competent designer tries to assign a tolerance to each dimension corresponding to the tolerance T. In that way, the designer tells the tool engineer which surfaces are most important.

The clarity and exactness of the language of dimensioning can be upheld by observance of the following rules, which the tool engineer has a right to expect the product designer to follow:

(1) Two points, lines, or surfaces on a drawing of a part should be connected only by one dimension or one set of dimensions.

(2) Dimensions should be placed between the points, lines, or planes most closely related to each other.

(3) Dimensions should be placed and tolerances assigned to reflect the functional requirements of the part.

(4) A part must be dimensioned in three coordinate directions.

3.4 CRITICAL AREAS

The surfaces given prime attention and preferred for locating and gaging in manufacturing are called *critical areas*. Before a process can be

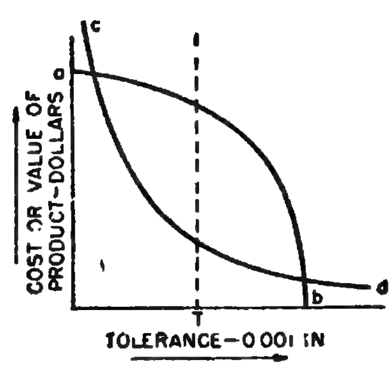


FIG. 10.6 THE FACTORS THAT DETERMINE A DESIRABLE TOLERANCE.

planned, the process engineer must select the critical areas. To do this, he applies three *indicators* that point to the functional and clearance surfaces on the part, because surfaces which serve the part functionally are likely to make the best critical areas for manufacturing. The indicators are:

(1) *The presence of a base line from which a number of dimensions are taken.* A base line must coincide with a real surface or an axis of a surface to be significant as a critical area.

(2) *Close tolerances* on linear or geometric dimensions.

(3) *Relatively fine surface finishes.* This might mean super-finished surfaces on a ground part or merely machined surfaces on an otherwise rough casting.

The indicators often point to several surfaces in each coordinate direction on a part as possible critical areas. For practical reasons, such as the size or position for location, a functional surface is not always a desirable critical area. Three *tests* are applied to determine which surfaces promise to serve best as critical areas from a practical point of view. The tests are:

(1) *A test for arithmetical superiority.* A surface that is the terminal point for the most dimensions is desirable as a critical area because it offers the best locating area to minimize tolerance accumulations.

(2) *A test for geometrical superiority.* A surface least subject to runout or with points far apart is desirable as a critical area.

(3) *A test for mechanical superiority.* A surface having a minimum susceptibility to deflection or mutilation is desirable as a critical area.

3.5 THE OPERATIONS OF A PROCESS

Manufacturing operations can be divided into the following classes:

(1) *Foundry operations* by which material is molded, formed, forged, cast, etc.

(2) *Enterprise protection operations* that control or expedite the manufacturing routine and protect the interests of the enterprise. Receiving, storage, and inspection are examples.

(3) *Critical manufacturing operations* concerned primarily with treating the critical area but also with treating all related surfaces as well.

(4) *Placement operations* that meet non-dimensional requirements like heat treatment.

(5) *Tie-in operations* that create sizes and forms needed for the placement operations and/or the finished part. Cutting of gear teeth, finish grinding, and drilling of small cross holes are examples.

(6) *Assembly operations* in which parts are put together.

Each item in the list of requirements for a process can be assigned to one class of operations. The problem of forming the operations is simplified because the operations need to be formed only out of the items in one class at a time.

One or several operations may be formed to satisfy the items allotted to any one class. Some operations should obviously be done together. For instance, several adjacent concentric diameters would normally be turned in one operation. Other items require separate operations because of the techniques and equipment involved. For example, if hardening and plating a piece are two items in the placement operation class, separate operations would be set up to take care of them. To a large extent, the amount of work that can be done economically in an operation depends upon the machine selected for the operation.

3.6 THE SELECTION OF MACHINE TOOLS

The work to be done determines what machines may be considered for an operation. If a number of surfaces are to be machined on a part, the choice is offered of machining them separately, all together, or in various combinations. The choice is narrow for one or two surfaces. If the surfaces on a part are similar in size, shape, and position, they are better suited to being

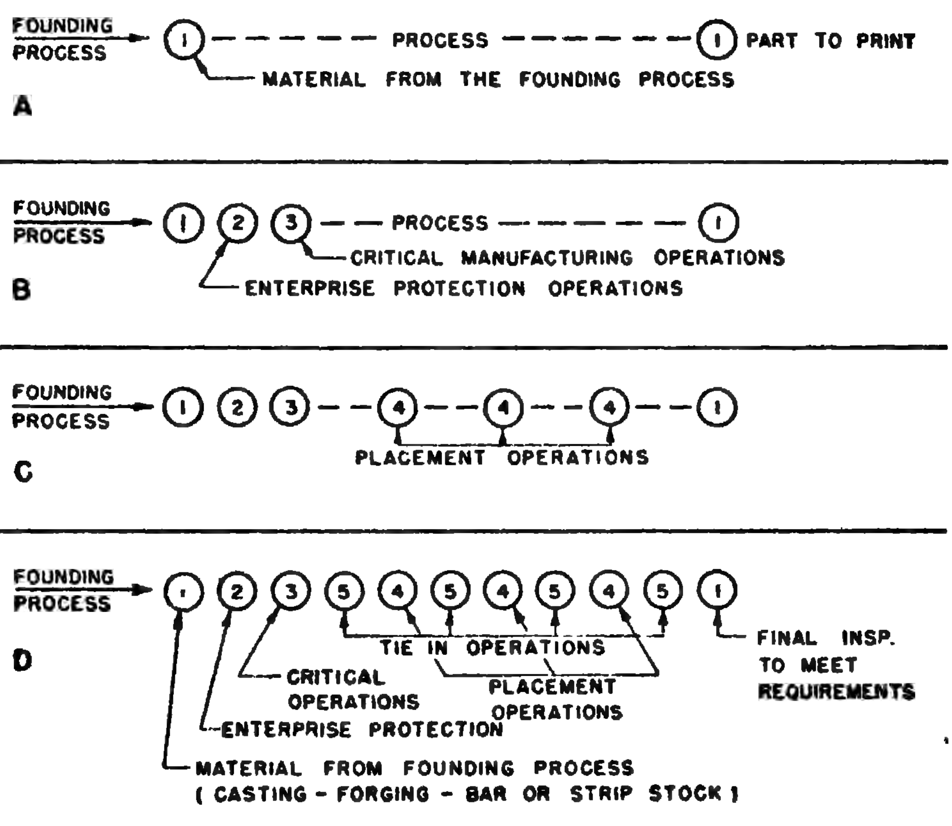
treated in one operation than if they are different from each other. Small tolerances call for certain types of equipment; large tolerances are not so exacting. Small workpieces are handled on equipment different from that used for large pieces. More powerful machines may be needed to work hard material than soft material.

The machines and equipment that will do a job at the lowest total cost are the ones that should be selected. Direct, overhead, and fixed costs should all be considered. Generally, the more items put into one operation, the less the handling time, the more the chance for simultation, and the lower the direct costs. At the same time, the operation is likely to be more complex and the equipment expensive. As a rule, a high rate of production justifies a large investment in equipment to reduce direct costs. The basis for a logical comparison of alternatives is given in Section 3.

To select a machine tool, an investigation must be made to ascertain the aptitude, range, and capacity required for the job. Each type of machine is best suited for certain kinds of work—lathes for turning, and drilling and boring machines for holes. A machine must have adequate range and capacity for the work it is to do, but not an excessive amount at unnecessary expense. The factors determining the range and capacity may be the size of workpiece, the working area, length of stroke or other motions, speeds and feeds, forces, energy, or power required. The last four factors will be discussed later. Information about ranges and capacities of specific machines are obtainable from manufacturers' quotations and catalogs.

Personal preferences or specific conditions may influence the selection of a machine tool. A particular type or make

FIG. 10.7 A DIAGRAM OF THE STEPS TO BE TAKEN TO SET UP THE SEQUENCE OF OPERATIONS OF A PROCESS.



Doyle, *Tool Engineering: Analysis and Procedure*, p. 364.

of machine may be favored because a person has in the past found it dependable, easy to operate, safe, or accurate. Often a new machine is not purchased if one almost as good is already in the plant and not fully loaded. However, a worn-out or obsolete machine may prove a decided handicap if it is selected merely on the basis of availability.

3.7 THE SEQUENCE OF OPERATIONS IN A PROCESS

The operations of a process can be arranged in proper sequence by the steps depicted in Fig. 10.7. In the first place, a process starts with founding operations. If they are not actually included in the process, their results must be recognized in the specifications for the rough workpieces The process is concluded by a final inspection operation. These are the terminal points of the process. The rough workpieces are inspected and stored, and enterprise-protection operations are set up for those functions.

A basic rule of processing is that the critical areas must be established as soon as possible to provide reliable surfaces for consistent location throughout the process. Thus, the critical manufacturing areas are the first machining operations and generally precede all placement operations. If placement operations are needed, they are inserted with ample space left for the others, as indicated in Fig. 10.7c.

Tie-in operations are placed as the purpose of each dictates its relation to the placement operations. All work should be done while the material is in its most workable condition for each type of operation. Where a number of tie-in operations fall into a group, they are arranged with respect to each other in the most economical manner, considering movement of materials, locations of machines, and the effect of each operation on others. Process flow charts and other graphic representations are used, especially in high-production industries, to analyze and refine processes with respect to material flow, and so forth. These techniques are discussed in Section 5.

If assembly operations are required, they are inserted in proper relation to the tie-in operations. As a final step, enterprise-protection operations are inserted to provide the desired control over the process.

4. CUTTING SPEEDS AND FEEDS

A process planner estimates cutting speeds and feeds to be able to designate machine speed and feed ranges and power, to select tools, and to estimate cutting time.

4.1 CUTTING SPEED

Cutting speed is the surface speed (C), in feet per minute, at which either the work or cutter travels. Machine speed (N) is usually specified in rpm where a workpiece or cutter of diameter (D) in. is revolved. A practical relationship is $N = 4C/D$.

The higher the surface speed of a cut, with other conditions constant, the faster the material is removed, but the more rapidly the tool wears and the more often it has to be replaced and resharpened. Tool costs become excessive with very high cutting speeds. More time than necessary is spent in making a cut with too low a speed. The optimum cutting speed for an operation is that which gives the lowest total cost and is different for each set of conditions.

The economical tool life for an operation is*

$$T = \frac{1-n}{n} \cdot \frac{C_2}{R_1} = \frac{5C_2}{R_1}$$

(for single-point tools)

where C_2 is the total cost of changing the tool on the machine and resharpening the tool and includes the

* L. E. Doyle, *Tool Engineering Analysis and Procedure* (New York: Prentice-Hall, Inc., 1950), p. 72.

TABLE 10.1 CUTTING SPEED RANGES FOR ORDINARY TURNING, FACING, BORING, SHAPING, PLANING, DRILLING, MILLING, AND BORING OPERATIONS

Work Material	Speed in Surface Feet per Minute						
	Aluminum	Brass	Cast Iron (soft)	Cast Iron (hard)	Steel (soft)	Steel (medium)	Steel (hard)
Tool Material							
High Speed Steel	400-1000	100-300	50-120	30-80	70-150	50-90	20-50
Cemented Carbide	1000-3000	300-800	200-400	100-200	150-400	150-300	75-150

proportion of the cost of the tool consumed in one sharpening. The factor R_1 is the operation rate for direct and overhead costs in dollars per minute; n is an exponent that according to Kronenberg has a value of 0.17 for most single-point tools. For milling, n is generally around 0.40.

The cutting-speed ranges of Table 10.1 for several kinds of work material and two common tool materials reflect typical practices in industry. The desirable speed in surface feet per min. (s.f.p.m.) for a particular operation depends upon the type of cutting tool, the properties of the work material, the feed and depth of cut, the use of cutting fluid, and the power and condition of the machine.

Form cutters that are hard to sharpen are run at relatively low speeds to make them last. Reaming is done at about one-half the speed of drilling to maintain the reamer size for an economical number of pieces. Most broaching is done at 10 to 30 s.f.p.m. On the other hand, simple multiple-tooth cutters, such as standard milling cutters, may be run faster than single-point tools because the wear is distributed over a number of teeth. Grinding wheels operate most efficiently from 4,000 to 15,000 s.f.p.m., as fast as each wheel will go without breaking.

Soft material can be cut faster than hard material for the same tool life. However, the structure of metals is quite as important. It has been shown* that cutting performance and tool life on cast iron may be improved fiftyfold by heat treatment to obtain optimum metallic structures; and on steel, tenfold.

Light finishing cuts are made at speeds 25 to 50 per cent higher than roughing cuts. Most economical results are usually obtained in roughing by removing large amounts of material with deep cuts and heavy feeds, up to the limit that can be withstood by the workpiece, tools, and machine. The speed is reduced to obtain an economical tool life, but more material is removed for a given tool life than would be obtained with higher speeds and lighter cuts.

4.2 DEPTH OF CUT AND FEED

Light cuts produce the best surface finishes. Depth of cut is usually less than $\frac{1}{16}$ in. for finish cutting and less than 0.010 in. for finish grinding. Finish turning and shaping feeds range from 0.005 to 0.025 in. per revolution or stroke.

Rough cutting is done most efficiently with cuts as large as the workpiece, tool, and machine will stand. As deep a cut

* Michael Field and Norman Zlatin, "Increasing Productivity in Production Machining," *S.A.E. Quarterly Transactions,* Vol. 6, April 1952.

as feasible with a light feed distributes the load over more cutting edge and generally is preferable to a shallow cut and heavy feed for a given cross-sectional chip area. Rough turning and shaping feeds range from 0.015 to 0.075 in. per revolution or stroke.

The size of a drill governs its feed, varying from 0.003 in. per revolution for a drill $1/16$ in. in diameter to 0.014 in. per revolution for a drill 1 in. in diameter. The feed of a reamer is generally two to five times that of a drill of the same size.

Feed on a milling machine is normally designated in inches per minute, but is based upon the chip load in inches per tooth, which ranges from less than 0.001 in. per tooth for thin saws and other fragile cutters to 0.015 to 0.025 in. per tooth for sturdy face mills.

For rough broaching,• the feed per tooth may be less than 0.003 in. for a weak broach to as much as 0.010 in. for a strong one. The cut per tooth is normally less than 0.001 in. in the burnishing or sizing section at the end of a broach and usually less than 0.0001 in. for the last few finishing teeth.

In traverse grinding, the wheel is fed from ½ to ¾ of its width for each revolution of the workpiece.

5. CUTTING AND FORMING FORCES

The force and energy required are important considerations in the selection of a press for a cutting or forming operation. In metal cutting, the forces are sometimes necessary considerations in the design of tools and machines. Bearings require special consideration in heavy duty machines.

5.1 BLANKING AND PIERCING FORCES

The maximum force in pounds required to cut a piece with a perimeter L in. from material t in. thick with an ultimate shear strength of S_s lbs./in.^{2} is $F_S = LtS_s$. Approximate strengths of common materials are given in Table 10.2.

The maximum force may be reduced by staggering several punches or by inclining the cutting edges of punch or die to provide shear. A punch needs to penetrate only a part of the thickness of a sheet equal to $p \times t$ to cut it. The *per cent penetration*, p, required for common materials is given in Table 10.2. If several punches are arranged in steps so that each acts only when the preceding one has penetrated a distance at least $p \times t$, the punches are said to be staggered, and the maximum force is only that imposed by the largest punch.

Shear on a punch distorts the blank or slug and on the die distorts the surrounding material. If the shear or height of inclination of v in. over the cutting edge is larger than $p \times t$, the force in pounds required to cut a piece is $F'_S = F_S \; tp/v$.

TABLE 10.2 PROPERTIES OF SHEET METAL*

	Soft			*Partly cold worked*		
Material	*Ult. tensile strength* #/in.^{2}	*Shear strength* #/in.^{2}	*Penetration* %	*Ult. tensile strength* #/in.^{2}	*Shear strength* #/in.^{2}	*Penetration* %
Aluminum (2S)	12,000	8,000	60	16,000	13,000	30
Yellow Brass	45,000	32,000	50	68,000	52,000	20
Steel 0.15 C	56,000	46,000	40	66,000	61,000	25
0.50 C	85,000	71,000	24		90,000	14
1.00 C	120,000	115.000	10		150,000	2
Steel, silicon		65,000	30			

* The values given are approximate and vary with material content, treatment, etc.

5.2 BENDING FORCES

When material of thickness t in. and ultimate tensile strength S lbs. per in.^{2} is bent along a single straight line of length L in. and the unsupported stock width is w in., the force* required in pounds is $F_B = Lt^2S/2W$.

A bend in a vee die with width of opening of w in. requires a force $F_B = Lt^2 \, S/W$. Sometimes this force is multiplied by 1.33 for a larger margin of safety. These are empirical formulas.

5.3 DRAWING FORCES

The force in pounds to draw a cup of periphery P in. from material with an ultimate tensile strength of S lbs./in.^{2} and thickness t in. should not exceed $F_D = PtS$.

5.4 PRESS RATINGS

About 10 per cent is usually added to the calculated forces to allow for losses in the press. As much as 25 per cent more may be added for springs, cushions, or buffers, especially for drawing, depending upon their sizes. The total force in pounds is converted to tons because presses are rated in tons. The tonnage capacity of a press may be found from the manufacturer's catalog. If that information is not available, the capacity in tons, T, may be calculated easily for a mechanical press with crankshaft diameter up to 7 in. For an end-wheel press with an overhanging crankpin of diameter D in., $T = 2\frac{1}{2}D^2$. For a press with crankshaft of diameter D supported on both sides of the crank (or double crank), $T = 3\frac{1}{2}D^2$. A press reaches its maximum capacity only when the ram is near the bottom of its stroke.

* John S. Brozek, "A Notebook on Die Design," *The Tool Engineer*, Vol. XXVI, No. 6, June 1951, 49.

5.5 METAL-CUTTING FORCES

The three conventional components of forces acting on a single-point tool are the feed or tangential force, F_c, in the direction of the cutting speed; a feed or longitudinal force, F_L, in the direction of feed and perpendicular to F_c; and a surfacing or radial force, F_R, at right angles to the other two.

Cutting force depends mostly upon the material cut and the cross-sectional area of cut, as designated in Table 10.3, and to a much less extent upon rake angles cutting fluids, tool materials, and speeds The force in an actual operation may be two to three times as high as that determined experimentally, because dull tools may as much as double the force, material is not always uniform, and heavier cuts may be taken in the shop than anticipated.

Longitudinal and radial forces are commonly less than the cutting forces in an operation but rise rapidly and approach the value of the cutting force

TABLE 10.3 AVERAGE VALUES OF CUTTING FORCE, F_c, IN LBS.*

Material	*Cross-sectional area of cut in square inches*				
	0.001	0.010	0.020	0.030	0.040
Light alloys (50 B.H.N.)	35	305	580	860	1120
Brass	129	725	1215	1650	2020
Cast Iron 100 B.H.N.	100	730	1330	1900	2440
150 B.H.N.	125	910	1660	2380	3050
200 B.H.N.	140	1020	1860	2660	3420
Cast Steel 150 B.H.N.	268	1900	3400	4830	6170
Steel SAE 1015	300	1920	3360	4570	5800
SAE 1035	400	2560	4480	6070	7700
SAE 1060	520	3330	5820	7900	10000

* Based upon equation $F_c = C_p \, (1000 \, A)^r$ and constants from Max Kronenberg, *Machining With Single Point Tools* (Cincinnati: The Cincinnati Milling Machine Co.).

TABLE 10.4 FACTORS FOR EQUATION $B = Kf^xd^y$ *

Material	*K*	*x*	*y*
Aluminum	50,000	1.1	1.2
C.I. (163 B.H.N.)	14,720	0.6	1
Steel SAE 1020	40,000	0.78	1
SAE 1045	42,000	0.78	1
SAE 1095	69,000	0.78	1
SAE 6150 (187 BHN)	53,400	0.78	1

* For values for other materials, see O. W. Boston, *Metal Processing* (New York: John Wiley & Sons, Inc., 1951).

when a tool becomes dull. Thus, the maximum values of F_L and F_R are likely to be close to the highest value of F_c.

Normally, over 95 per cent of the horsepower, P_c, in a metal-cutting operation is derived from the cutting force, F_c lbs., and the cutting speed, V ft. per minute, which act in the same direction. That is because the cutting speed is much larger than the feed rate. For many operations, the cutting force can be conveniently and closely estimated from the relationship

$$F_c = \frac{33000P_c}{V}$$

In a milling operation, F_c is the tangential force on the rotating cutter. For a drill, the torque, T in. lbs., is related to the speed, N rpm by

$$T = \frac{63000P_c}{N}$$

The thrust of a drill can be represented by

$$B = Kf^xd^y$$

where f is the feed in inches per revolution, and d is the diameter of the drill n inches. Experimentally determined values of k, x, and y are given in Table 10.4.

6. ENERGY AND POWER

The energy and power that must be delivered by a machine determine the rate at which the machine can do a job or whether it can do the job at all.

6.1 ENERGY AND POWER IN PRESS WORK

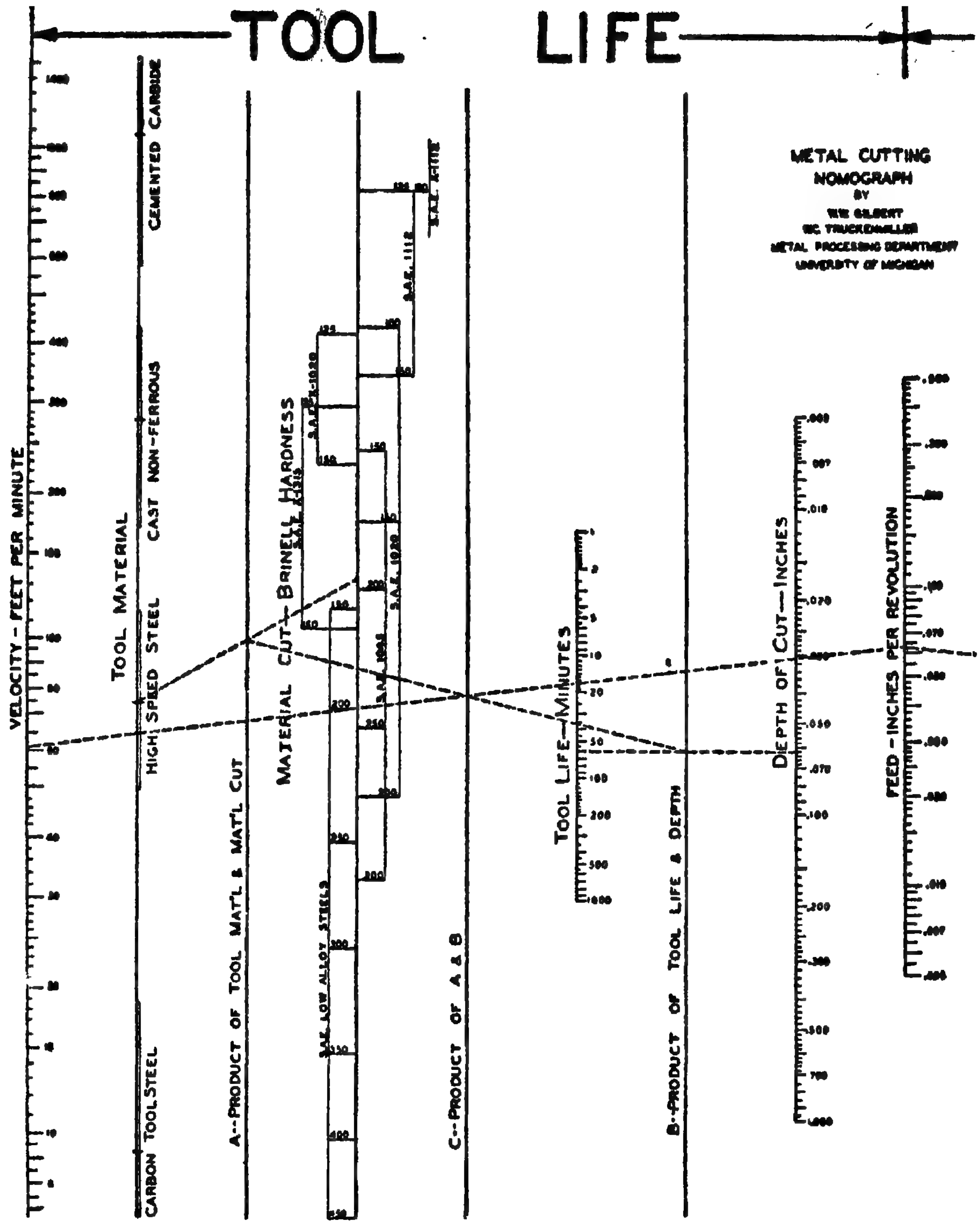
The energy a press must deliver may be approximated by the product of the maximum force, F_s lbs., times the distance the material is penetrated or drawn. The energy in ft. lbs. per stroke to shear a material of thickness t in. with a per cent penetration p is $E = F_s tpk/12$. A value of 1.16 is commonly accepted for the factor k to cover losses from machine friction, pushing slugs through the die, and so forth.

With a mechanical press, energy is obtained from slowing down the flywheel at each stroke. A loss of speed of 10 per cent is considered satisfactory for continuous operation, and a flywheel of weight W lbs. with a maximum speed of V ft. per second at its radius of gyration delivers energy in ft. lbs. per stroke of $E_c = 0.003WV^2$.

A loss in speed of 20 per cent is commonly allowed for intermittent operation. Then the energy in ft. lbs. per stroke delivered by the flywheel is $E_I = 0.0056WV^2$.

The horsepower that must be delivered by the motor to restore the energy, E, in ft. lbs., used at each stroke with the press operating at N strokes per minute is

$$P = \frac{E \times N}{33000}$$



SAMPLE CALCULATIONS

GIVEN:

TOOL MATERIAL - - - - - - - - - HIGH SPEED STEEL
MATERIAL CUT - - - - - - - - - 100 B.H.N. - SAE 1020 STEEL
DESIRED TOOL LIFE - - - - 60 MINUTES
DEPTH OF CUT - - - - - - - - - - - 0.0625 INCHES
FEED - - - - - - - - - - - - - - - - 0.0625 INCHES PER REV.

READ FROM CHART

VELOCITY = 66.5 FEET PER MINUTE

MAXIMUM OUTPUT

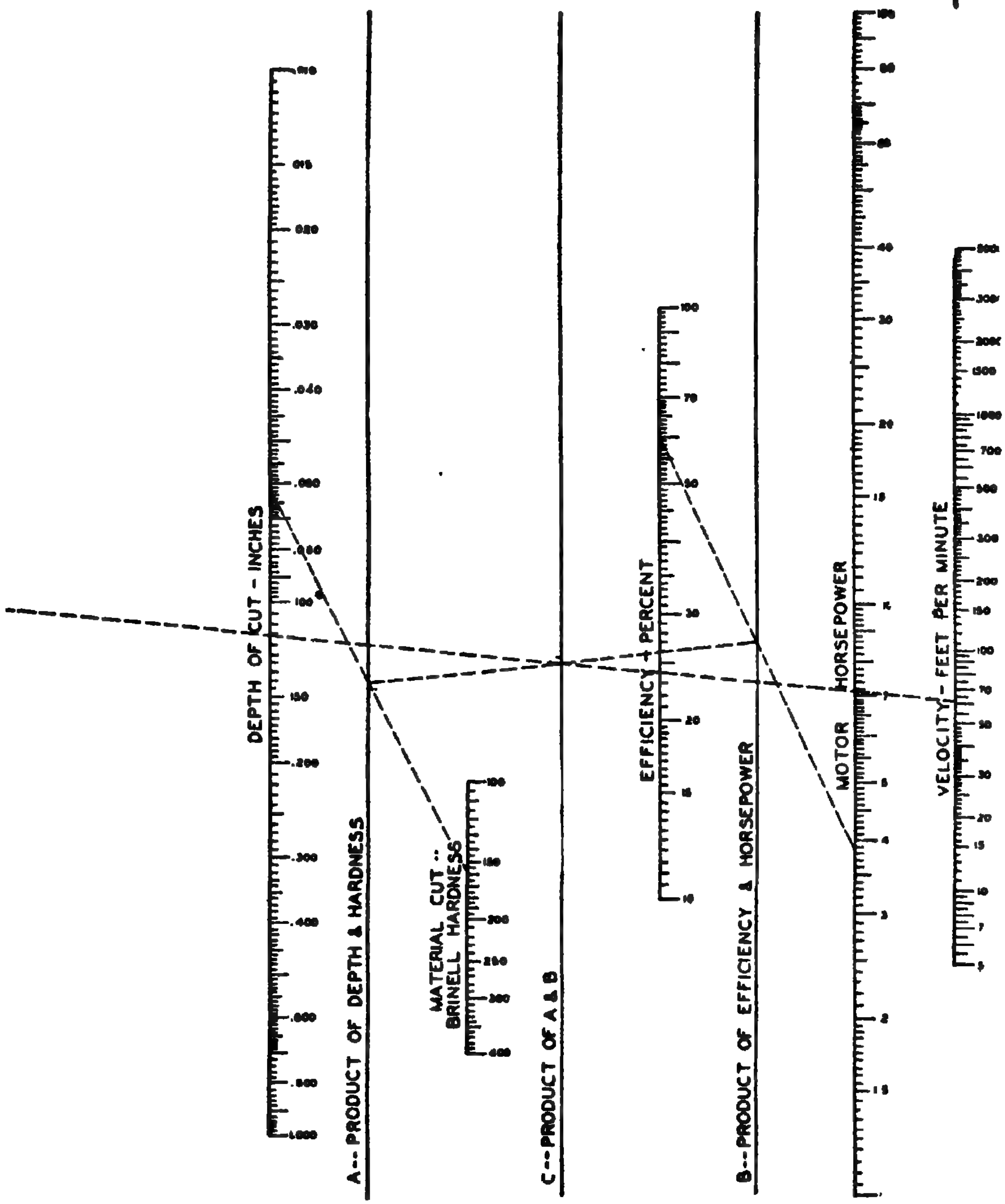
GIVEN:

TOOL MATERIAL
MATERIAL CUT
TOOL LIFE
DEPTH OF CUT
(DEEPEST CUTS MOST EFFICIENT)
MACHINE EFFICIENCY
MOTOR HORSEPOWER
(USE RATED HORSEPOWER)

THE FEED SHOULD BE VARIED UNTIL THE VELOCITY ON THE TOOL LIFE SIDE IS EQUAL TO THE VELOCITY ON THE POWER SIDE. THIS FEED AND SPEED WILL GIVE THE MAXIMUM METAL REMOVAL FOR THE GIVEN CONDITIONS.

FIG. 10.8 A NOMOGRAPH OF THE VARIABLES IN TURNING WITH SINGLE POINT TOOLS.

POWER



SAMPLE CALCULATIONS
POWER

GIVEN:

FEED ------------------ 0.0625 INCHES PER REV
VELOCITY -------------- 80.5 FEET PER MINUTE
DEPTH OF CUT ---------- 0.0625 INCHES
MATERIAL CUT ---------- 180 B.H.N. - SAE 1020 STEEL
MACHINE EFFICIENCY ---- 60 PERCENT

READ FROM CHART:

MOTOR HORSEPOWER = 3.75

W. W. Gilbert and W. C. Truckenmiller, "Metal Cutting Nomograph," *Mechanical Engineering*, Vol. 65, December, 1943, p. 893.

TABLE 10.5 APPROXIMATE VALUES OF HORSEPOWER REQUIRED TO REMOVE ONE CUBIC INCH OF MATERIAL PER MINUTE UNDER AVERAGE CONDITIONS

	Machining operation			
Workpiece material	*Single point tool (Turning, shaping, etc.)*	*Drilling*	*Milling*	*Grinding*
Aluminum	0.3	0.5	0.6	
Brass	0.3	0.5	0.7	
Cast Iron (Soft)	0.3	0.6	0.8	8
Cast Iron (Hard)	0.5	0.9	1.0	8
Steel (Soft)	1.0	1.2	1.5	8
Steel (Medium)	1.4	1.6	1.9	11
Steel (Hard)	1.8	2.0	2.2	14

6.2 POWER IN CUTTING METAL

The unit or specific power consumption in metal cutting is expressed in horsepower per cubic inch per minute. The power varies with the material, the type of operation, the size and shape of cut, the shape and condition of the tools, the cutting speed, and the cutting fluid. Average values of unit horsepower for common materials and machining operations are given in Table 10.5. The unit power consumption for a fairly light cut is approximately two to three times what it is for a heavy cut. As tools become normally dull, unit power consumption can be expected to increase up to 50 per cent. Increases in rake angle and cutting speed tend to reduce the unit power consumption, but only slightly within practical amounts of variation.

The horsepower consumed at the tool point is the product of the unit horsepower times the cubic inches of material removed per minute. The motor of a machine tool must furnish the power lost in the machine as well as that consumed at the tool point.

Satisfactory practice is to operate a machine tool at rated power capacity for continuous service. Machines frequently are overloaded without harm for intermittent operation—up to 75 per cent over rated capacity when the idle time between cuts at least equals the cutting time.

7. THE VARIABLES OF METAL CUTTING

The nomograph of Fig. 10.8 gives a summary of the effects of tool and work material, depth of cut, machine efficiency, feed, and cutting speed upon the length of life and power consumption of single-point cutting tools. The example worked out on the chart explains its use. The chart is based upon an assumed power increase of 35 per cent for dull tools, as compared with newly ground tools. Power consumption is charted only for plain carbon steel. Heavy feeds generally are called for by solutions given by the chart and may have to be compromised in some cases to conform to the strengths of the workpieces, tools, and machines.

8. WORKPIECE LOCATION AND CLAMPING

The locating points and surfaces and clamping areas on a workpiece are selected when a process is planned for the reason explained in item (3) of Art. 2.2. The actual locating and clamping devices are selected and proportioned in tool design.

8.1 WORKPIECE LOCATION

The conditions for full workpiece location are given by the 3-2-1 principle of location, as follows: *To*

locate a piece fully, place and hold it against three points in a base plane, two points in a vertical plane, and one point in a plane square with the first two. The three points for the base plane may be on parallel surfaces if occasion demands, as may be the two points for the second plane.

The three planes or three sets of planes for locations should be mutually perpendicular if possible. Such surfaces, or points on them, provide a box-like arrangement in which a part can be held most securely. Also errors from foreign particles on the locators are minimized.

Points as far apart as possible on any surface should be selected to help minimize locating errors.

Fewer than the number of points specified by the 3-2-1 principle may be selected to locate a piece if partial location is sufficient, as it often is. For instance, a chuck normally locates a piece to be turned on the equivalent of four or five points. However, a free body has six degrees of freedom, and a locating point is necessary for each degree of freedom to be confined.

No more than the numbers of points prescribed by the 3-2-1 principle of location should be selected for locating a rough surface because more points provide unreliable location. However, more points than specified by the 3-2-1 principle, even whole surfaces, are often desirable for a finished surface. The extra points add nothing to location but do provide better support to the workpiece. On four buttons, a finished surface rocks if a chip is present on one of the buttons, but no evidence of the chip is given with three buttons.

A part should be located in an operation from surfaces most directly connected dimensionally to the surface or surfaces treated in the operation to minimize the accumulation of tolerances.

When the critical areas are machined on a rough workpiece, the locating surfaces should be selected to insure (1) that a reasonable relationship exists between rough and finished surface on the finished part, (2) that thickness of sections is uniform, and (3) that adequate stock will be left on surfaces to be machined later.

In tie-in operations, a part should be located from critical areas. If these areas are distorted in placement operations, they should be re-established by going back to the basic rough locating areas or to areas reliably related to the critical areas.

8.2 WORKPIECE CLAMPING

The purpose of clamping is to direct forces to seat a workpiece firmly against the locating points and surfaces and to hold it there securely against all disturbing forces.

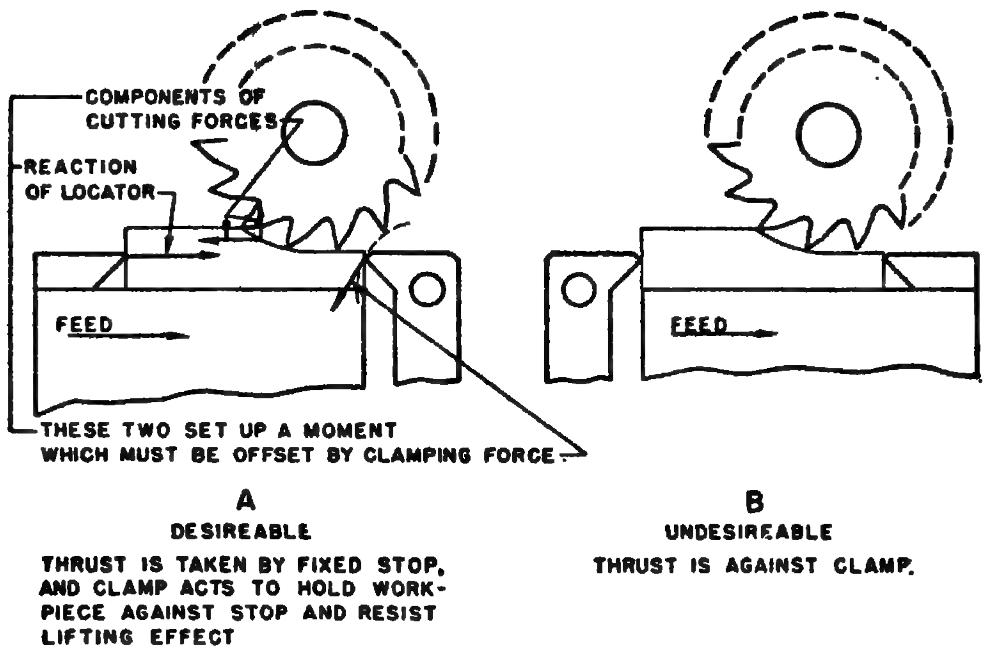
Clamping forces must be applied to suit the locators. A clamping force must neither tend to upset the location of the workpiece nor tend to distort the workpiece. The best condition prevails when a force is directly opposed by a fixed locator through a heavy section of the workpiece. Otherwise, a clamping force should be counteracted directly by a jack support, especially if the workpiece is weak and likely to deflect. A clamp may dig into a rough surface but must not mar a finished surface to which it is applied.

Processing forces should be directed against fixed locators as much as possible, as indicated in Fig. 10.9. Clamping forces are applied to counteract processing forces not taken directly by fixed stops and to neutralize the moments set up by the processing forces. Initial clamping forces must be imposed to prevent even the slightest movement of a workpiece in an operation. To do that, the initial force must be larger than any reaction the clamp is likely to receive during the operation.

9. PRODUCTION TOLERANCES

9.1 OPERATION TOLERANCE

The natural tolerance or performance limits of an operation set up and conducted in a definite manner can



Doyle, *Tool Engineering: Analysis and Procedure*, p. 452.

FIG. **10.9** FORCES OPPOSED BY FIXED STOPS.

be ascertained by the techniques of statistical quality control described in Section 13.

Definite tolerances must be held in each operation if a process is to produce finished parts within specified tolerances. As indicated in Fig. 10.6, a dimension can be held to any tolerance desired, but the cost increases as the tolerance is decreased. Usually, different kinds of operations are necessary for different tolerances. For instance, a diameter may be turned if its tolerance is more than 0.001 in., but must be ground for a smaller tolerance, and must be lapped or superfinished for exceptional accuracy and finish.

The dimensional variations experienced in an operation result from a number of causes of error. These must be recognized and controlled to establish an operation capable of producing within desired tolerances. The basic causes of error are:

1. Variations in rough workpieces coming to an operation.
2. Variations in material hardness, structure, etc.
3. Defects in tools and machines.

Tool dimensions must have tolerances if their costs are to be reasonable; common practice is to give a tool dimension a tolerance of 5 to 20 per cent (most commonly 10 per cent) of the tolerance on the corresponding workpiece dimension. Many tools can be designed in a number of ways, each offering a different degree of accuracy. The cost of a tool generally increases with the accuracy required. A responsibility of the process planner is to prescribe designs most suitable for the accuracy required in each operation.

4. Wear. Good practice calls for wear-resisting inserts at strategic places in tools. If the rate of wear of cemented carbide is 1, then hard nonferrous alloys wear approximately 15, hardened alloy steel 25, and hardened plain carbon or case-hardened steel 25 times as fast.* Hard surfaces need not be large to wear long. A small surface does not wear appreciably faster than a large one if the bearing pressure is kept below 25 pounds per square inch. Hard surfaces are lapped or superfinished after grinding for greatest wear resistance. Uniform wear is much less damaging than local-

* E. E. LeVan, "Wear of Metallic Surfaces," *Metals and Alloys*, Vol. 8, No. 7, July 1937, 206.

ised wear. Adequate shields and guards should be provided whenever possible on tools and machines to keep out abrasive substances that promote wear.

5. Deflection. Variations in deflection cause errors in dimensions. Compensation can always be allowed for constant deflection. If deflections are small, variations in deflection are correspondingly small. Deflection is controlled by making rugged and heavily ribbed tools and by supporting workpieces adequately. However, it is important that devices employed to prevent deflection, such as jack screws, do not themselves introduce additional deflection. Tools should be arranged so that deflection-inducing forces are transmitted to rigid basic members.

6. Thermal expansion. The results of thermal expansion are most pronounced when different metals are used together. Thermal expansion can be minimized by the use of sharp cutting tools, provision for adequate heat dissipation, uniformity of power consumptions at different stations of an operation, use of cutting fluid, and controlled room temperatures.

7. Dirt, chips, and burrs. Considerations in designs to help this condition are suggested in Art. 14.3. In operation, cutting fluid or air should be directed to keeping locating surfaces clean.

8. Lack of skill. Facilities must be provided to suit the level of skill available for each operation, and operator training must not be overlooked. Often a tool engineer is able to get good performance on the equipment he provides by taking the pains to see that the operator is told how to operate it properly.

9.2 TOLERANCE CHARTS

A tolerance chart is a means of proving that the operations as planned will together produce the tolerance required for the product. It shows the dimensions, tolerances, and stock removal at all stages of manufacture in an easily understood form, saves time in making changes, and serves as a ready reference during discussions of a process.

The typical tolerance chart of Fig. 10.10 shows conventional designations, symbols, and notations. An X at one end of one dimension arrow in each operation shows the locating surface. The head of each arrow points to a line representing the surface cut. Lines without arrows represent resultant dimensions.

On the chart of Fig. 10.10, the tolerances on stock removal and resultant dimension are the sums of tolerances of working dimensions. For instance, the ± 0.002 in. tolerance of the 3.007 in. resultant dimension of Op. No. 20 is the sum of the ± 0.001 in. tolerances of the 0.118 in. and 3.125 in. working dimensions of Op. Nos. 5 and 20. In the event that operations are subject to statistical quality control, with assurance that the deviations in the working dimensions are likely to occur at random within the specified working limits, the probable tolerances of the resultant dimensions and amounts of stock removal may be computed on the basis of $A = \sqrt{B^2 + C^2}$. The resultant tolerance is A, and the working tolerances are B and C. On this basis, the tolerance of the 3.007 resultant dimension of Op. No. 20 can be expected to be $\sqrt{0.002^2 + 0.002^2} = 0.0028 = \pm 0.0014$ in.

A tolerance chart must be realistic and take into consideration that:

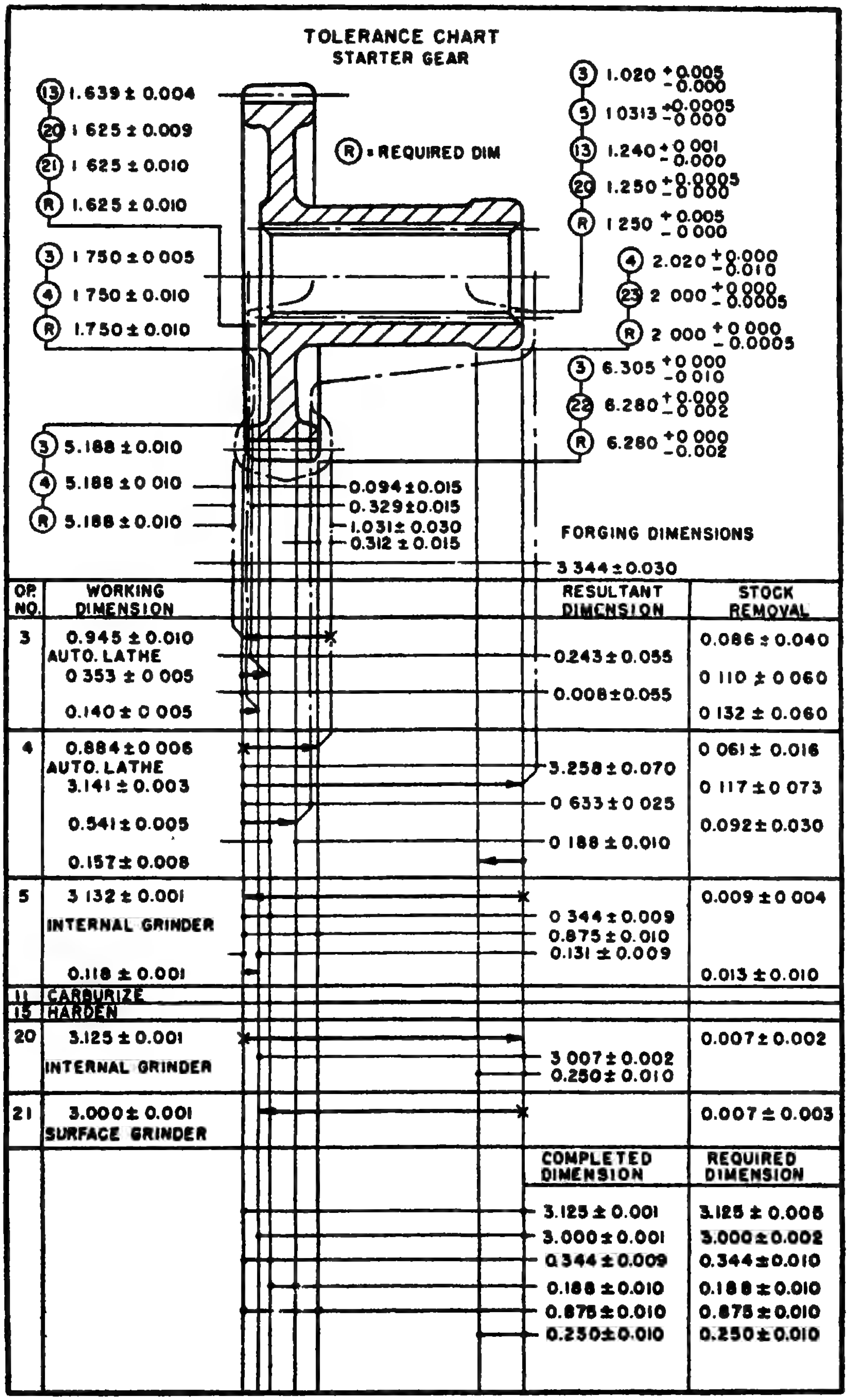
1. Any condition contrary to good practice must not be allowed merely to satisfy the tolerance chart.

2. Tolerances must reflect economically attainable performance for each operation.

3. Tolerances specified from a surface which is neither a locator nor machined in the same operation must be large enough to absorb the accumulation of tolerances.

4. Dimensions must be chosen so they can be checked with a practicable gage, preferably both in the holding device and after release.

5. The least stock allowed must be enough to insure cleanup of a surface,



Doyle, *Tool Engineering: Analysis and Procedure*, p. 485.

FIG. 10.10 A TYPICAL TOLERANCE CHART.

and the most stock must not be excessive.

If a tolerance chart shows that tolerance accumulations are likely to exceed specifications or that some operations must be held too closely, the following remedies may be presented:

1. Operations may be recast or rearranged.
2. Corrective operations may have to be added.
3. The sequence of operations may be changed.
4. The fact may be recognized that some part of the production may be outside of specifications.
5. Stock-allowance requirements may be waived to some extent.
6. An attempt may be made to have the tolerance of one or more dimensions increased on the part drawing. The tolerance chart may serve as proof of the impracticability of meeting specifications.

9.3 STOCK ALLOWANCE

The material provided on a surface to be machined is called the stock allowance and must be sufficient to allow for expected runout and variations of the workpieces and enable the tools to cut cleanly.

If a plane surface is 0.005 in. out of parallel with its locating surface, a difference in stock allowance of 0.005 in exists from one end to the other. Likewise, the effective material on a surface between centers is equal to the total material on the diameter less the total indicator reading of runout. In addition, rough surfaces have valleys, scratches, scale, inclusions, or burnt material that must be removed completely to leave a good finish.

In many cases, definite upper limits for stock allowances must be observed. Good surface finishes and dimensional accuracy demand light cuts. Even in roughing, too much stock can impose excessive loads on tools and shorten their lives. The case hardness of carburized steel parts is impaired by too much stock removal.

Stock allowance often depends upon the tolerances that must be accepted from preceding operations, especially from founding operations. Surfaces to be machined on a casting should preferably be cast in the drag section of the mold, because surfaces cast in the cope can be expected to vary more. Tolerances for forgings are specified by the *Standard Practices and Tolerances for Impression Die Forgings* adopted by the Drop Forging Association.

In general, the larger a workpiece, the greater the stock allowance.

The proper amount of stock allowance for any particular operation must be determined from the considerations applicable to the specific case. As a guide, Table 10.6 shows typical stock-allowance practices for common operations.

10. PLANNING AND TOOLING FOR LOW-COST PROCESSING

Direct, indirect, and fixed costs must all be taken into account in planning a process. A low direct cost may be realized with labor-saving equipment entailing high fixed cost. On the other hand, direct costs may be high when inexpensive equipment is used. In each case, that balance of the components must be found that results in the lowest total cost, the same as for any engineering project, as explained in Sec. 8. In addition, a process must be planned and tooled so that all costs are as low as possible, whatever the relationship among them. Definite principles point to the ways of achieving low costs.

10.1 OPERATION ANALYSIS FOR LOW DIRECT COSTS

An operation is analyzed by being broken down into its elements. Each element is studied to find out how it can be done best. The tested elements are put together in the most efficient way, and facilities are provided to carry out the operation as planned.

For convenience, the elements of an

TABLE 10.6 TYPICAL STOCK ALLOWANCES FOR MACHINING OPERATIONS

(Specifications are for stock on surface or side unless otherwise stated)

Condition of rough surface	*Metal removal process*	*Dimension*			
		Up to 2″	*2″ to 6″*	*6″ to 12″*	*12″ to 18″*
Iron Casting	Turning or Milling	1/16	3/32	3/32	1/8
	Boring (dia. allow.)		1/8	1/8	3/16
Steel Casting	Turning or Milling	3/32	1/8	1/8	3/16
	Boring (dia. allow.)		3/16	3/16	1/4
Malleable Casting	Turning or Milling	1/32-1/16	1/16	3/32	5/32
	Boring (dia. allow.)		1/16	3/32	5/32
	Coining	0.15-.030			
Drop Forging	Turning or Milling	1/64-3/32	3/32-1/8	1/16-1/8	
	Coining	.015-.030			
Die Casting	Reaming (dia. allow.)	.005-.030			
	Diamond Boring (dia. allow.)	.008-.025			
Rough Turned Steel	Finish turning (dia. allow.)	1/64-1/32	1/32-3/64	3/64-1/16	1/16-3/32
Rough Machined	Grinding (dia. all.)	.010-.015	.012-.015	.015-.020	.018-.020
	Grinding (surface)	.005-.008	.007-.010	.010-.012	
Rough Ground	Grinding (dia. all.)	.008	.010	.015	.018
	Grinding (surface)	.003-.005	.004-.007	.005-.010	.006-.010
Finish Ground	Micro Grind (dia. all.)	.004	.005	.007	.008
	Micro Grind (surface)	.002-.003	.002-.003	.003-.004	.004-.005
Commercial Grind	Superfinish	.00025	.0003		
Smooth Grind	Superfinish	.00015	.0002		
Drilled Hole	Boring (dia. all.)	1/32-1/16			
	Reamed (dia. all.)	.010-.035			
Bored Hole	Precision (dia. all.) Boring or Reaming	.004-.009			

operation may be classified as handling elements and machine elements. The former are those done by the operator, such as loading, unloading, and clamping. The latter are those performed by the machine and tools. The major direct costs in most operations arise from these two activities.

10.2 DIRECT HANDLING COSTS

The costs of handling elements can be minimized by motion economy, elimination of strain, fatigue, and heavy manual labor, conservation of skill, and combination of elements.

The principles of motion economy* of most importance to tool engineering are: (1) eliminate all unnecessary motions, (2) shorten and simplify all necessary motions, (3) balance the work, (4) minimize use of the eyes, and (5) eliminate use of hands as holding devices. The subject of motion economy and techniques employed for operation analysis are discussed in Section 5.

* O. W. Habel and G. G. Kearful, "Machine Design and Motion Economy," *Mechanical Engineering*, Vol. 61, No. 12, December 1939, 897. Also *Motion Economy Rules To Guide Process and Tool Engineers* (Saginaw Steering Gear Div., General Motors Corp.).

Strain, fatigue, and heavy labor may be alleviated by providing (1) comfortable working conditions, (2) convenient and easy-to-operate controls and devices, (3) mechanical power to do work, and (4) means to reduce the weight or load an operator must bear.

Skill is conserved by transfer of skill and improvement of perception. Skill is transferred when built into a machine or tool, such as a drill jig. Perception is improved by magnification of movements, as by indicators.

Elements are combined by simultation and integration. Simultation means the occurrence of two or more elements at the same time, such as when machine and operator are both working at once. Integration means the incorporation of two or more cuts or actions into one operation, even though they may not be done simultaneously. Machining as well as handling costs may be reduced by combining elements. Special machines are commonly built for high production to carry out these principles.

10.3 DIRECT MACHINING COSTS

Machining time is influenced by the design of the workpiece, the machining method, the capacity of the machine, the design of the tools, the condition of the work material, and the conduct of the operation.

Design changes to reduce machining time are suggested in Art. 3.2 and Fig. 10.5.

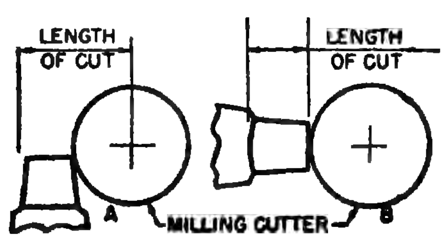
Some machining processes are quicker than others under favorable circumstances. For instance, broaching is faster than milling but can be applied only to parts offering no obstruction to the broach and produced in sufficient quantities to justify the investment in broaching equipment.

The maximum attainable machining rate may depend upon the strength and power of the machine tool. Rugged and powerful machines are necessary to produce pieces in large quantities. With adequate machine capacity, carefully designed cutting tools are necessary to realize the most from an operation. As an example, a manufacturer found that the rate of a milling operation could be increased appreciably by increasing the number of teeth in the cutters over conventional designs in use for some time. Another requirement for fast machining rates is the use of heavy jigs and fixtures to give adequate support to the work.

The factors of work material, speed, feed, and depth of cut that affect cutting rates are discussed in Art. 4. An equally important factor in the conduct of an operation is the distance the cutter or work must move while cutting and also while not cutting.

A workpiece should usually be cut in the direction requiring the shortest travel. For instance, the time for milling tangs on collets was reduced by cutting in the manner shown at *B* rather than *A*, in Fig. 10.11. An exception to this rule is found in planing or shaping, where the cut is taken in the longest direction to cover a surface in the fewest number of strokes. Tools should be moved to and from the work fast and over as short a distance as is safe. Most modern machine tools are provided with rapid traverse rates for this purpose.

FIG. 10.11 SHORTENING THE LENGTH OF A MILLING CUT.



10.4 ECONOMY OF INDIRECT COSTS

The tool engineer can contribute to low overhead costs by planning and providing facilities to aid the auxiliary functions of production, promote safety, and coordinate each operation with the material-handling facilities between operations.

Inspection can often be facilitated by providing means to check work at the point of operation, even before it is removed from the machine, in order to uncover defective tendencies before they have gone on too long.

Scrap disposal can be expedited by mechanical means for segregating chips and scrap from the finished work, by readily cleanable equipment giving easy access to accumulations of chips and scrap, and by means to carry scrap from machines to collection centers, such as by chip conveyors where warranted.

Setup, changeover, and maintenance are aided by flexible and versatile tooling, by preset tooling, and by readily accessible arrangements, such as racks, for reserve tools. Upkeep and repair costs are reduced by designing tools for easy repairing and servicing. Parts subject to wear should be easily removable and replaceable.

A machine or tool that is readily obtainable is usually preferable, at least on a temporary basis, to a more efficient one that may take time to procure. Nothing is so expensive in industry as not producing at all.

10.5 ECONOMY OF FIXED COSTS

The cost of equipment for an operation can be kept at a minimum by making it as simple as feasible to produce the required quality and quantity of product, by using toolmaking facilities judiciously, by using versatile equipment, by making use of standard tool details, and by adapting standard machine units for construction of special machines.

With other factors constant, the amount of production determines how complex and refined a tool should be. Commonly recognized classes of tools for various levels of production are described in Art. 12.1. A tool should not be made appreciably better than needed.

The cost of a tool usable for only one job must be regained entirely from that job. Low-cost tooling is often devised by making minor additions to general-purpose tools easily changed over to other work, such as special jaws for vises, as in Fig. 10.21.

Standard tool details, available commercially, are low in cost, quickly available, fully developed, and thoroughly tested. Standard commercial holding devices, cutting tools, gages, and jig, fixture, and die details are more economical than special items. The universal jig of Fig. 10.22 is an example.

Most machine tools are assembled from units such as headstock, base, and ram. Special machines are commonly constructed from standard machine units with the addition of a few special details. This is known as *unit construction* and is more economical than building a machine entirely from special parts.

11. COST ESTIMATING

Cost estimating may be done to establish the selling price of a product, ascertain whether a proposed product can be manufactured and marketed profitably, determine how much must be invested in equipment, find whether parts or assemblies can be more cheaply fabricated or purchased, determine the most economical process, tooling, or material for making a product, and establish a standard of performance at the start of a project.

Sometimes a distinction is made between product and tool cost estimating. The former is concerned with merchandise to be sold, the latter with equipment for production. Product or tool cost estimating may be preliminary or final. Preliminary cost estimating usually is done before product designs or production plans have been completed, and is rougher than final estimating.

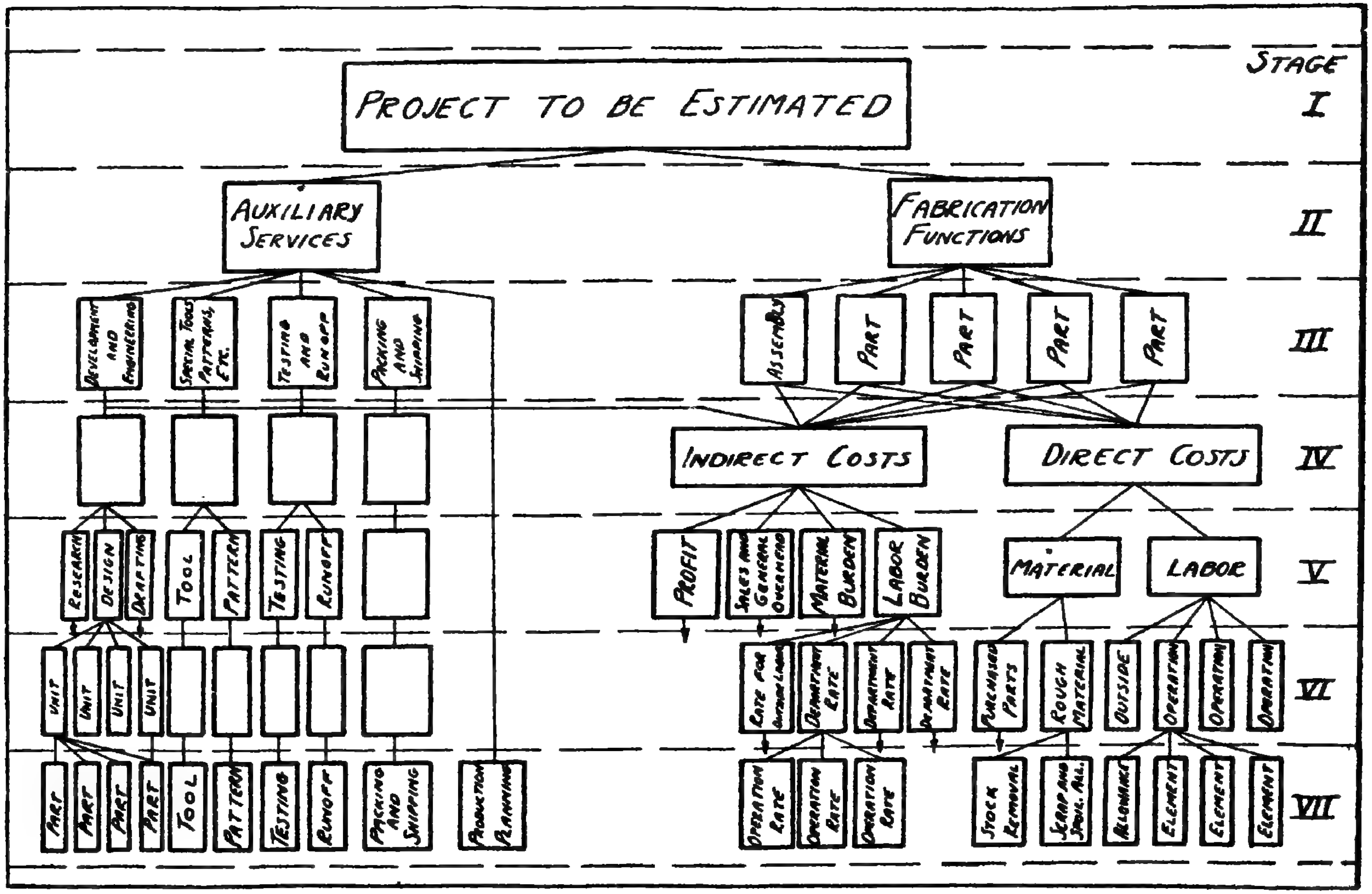
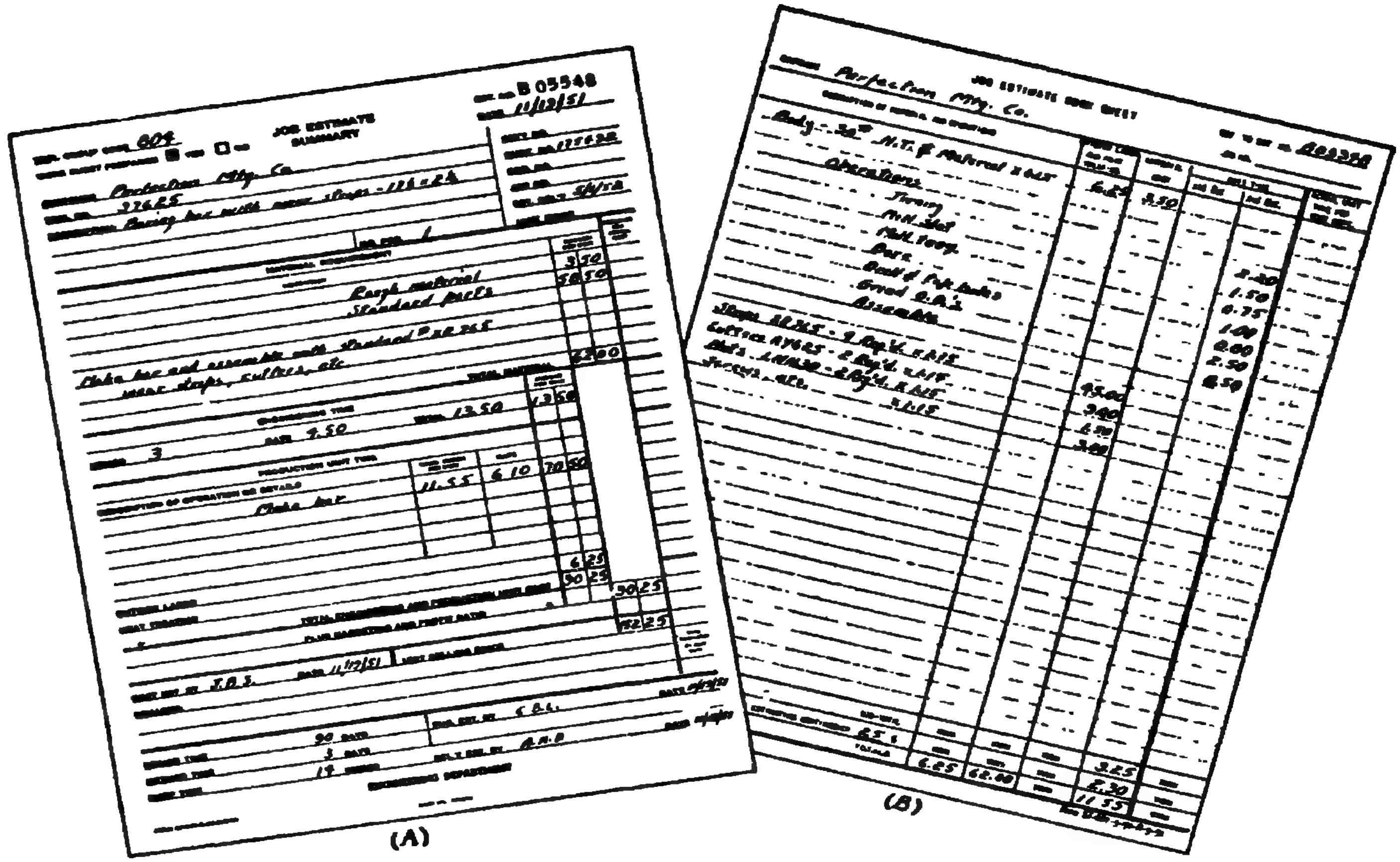


FIG. 10.12 WAYS OF BREAKING DOWN A PROJECT INTO ELEMENTS TO ESTIMATE ITS COST.

Paper T9-1, 1952, The American Society of Tool Engineers.



Paper T9-1, 1952, The American Society of Tool Engineers.

FIG. **10.13** (A) A COST ESTIMATE SUMMARY SHEET.
(B) A COST ESTIMATE WORK SHEET.

11.1 ESTIMATING PRACTICES

The cost of an item may be estimated by comparison or by a unit-rate computation. By the first method, the item is compared with similar items of known cost. By the second method, the number of units of a property of the item is multiplied by a unit cost. For instance, the material cost of an article is commonly estimated by multiplying its weight by the unit cost of the material in dollars per pound.

A project may be estimated quickly as a whole, as indicated by stage I of Fig. 10.12, but this procedure is often inaccurate because past experience with similar projects may not be available, comparable subjects may be quite different in detail, the quantities produced may be different, or overhead, labor, and material rates may have changed. For accuracy and reliability, most projects are broken down into elements, the costs of which are estimated individually and added together.

Typical degrees to which projects may be broken down are indicated by the stages of Fig. 10.12. In explanation, a breakdown to stage VI means that the direct time for each operation on each part is estimated on the basis of the time required for similar operations. The time for each type of operation is multiplied by a certain direct labor and overhead rate. Time for outside labor, if required, is estimated and multiplied by the prevailing rate. The costs of purchased parts and rough material are estimated separately and multiplied by appropriate burden rates. Desired amounts are added for sales and general overhead and profit. The costs of auxiliary services, such as development, engineering, tools, patterns, and testing, are estimated separately for the major units of the project.

Each stage of Fig. 10.12 represents a general form of estimating practice, but some variation can be found in almost every plant. For instance, one procedure could be to estimate direct labor and material by a breakdown corresponding to stage VI, indirect costs at stage V, and auxiliary services at various stages as convenient. As a general rule, tool estimating is done at stages I through VI, and product estimating at stages V through VII.

The results of an estimate are commonly presented on a form such as that exemplified in Fig. 10.13. The estimating form, particularly a summary sheet, generally does not reveal the full extent of breakdown in the estimate.

11.2 ESTIMATING MATERIAL COSTS

The material chargeable to a piece is that in the rough state and includes all scrap removed. If a piece is machined, the stock thickness on the sides is added to the finished dimensions from which volume is calculated. An irregular piece is divided into simple parts. Volume is multiplied by the density of the material (0.26 pounds per cubic inch for cast iron, 0.28 for steel, 0.092 for aluminum, 0.30 for yellow brass, and 0.31 for red brass) to find the weight. Experienced estimators are able to judge the weights of intricate pieces rather closely by comparing them with pieces of known weights.

The length of bar stock required for a piece is the sum of the length of the finished piece plus 1/32 to 1/16 in. on each faced end of the piece plus cutoff stock equal to the width of cutoff tool, as specified in Table 10.7. The length of bar stock is multiplied by the weight per inch or price per inch for the particular diameter of bar.

The dimensions of a blank developed from a formed piece, as explained in Art. 15.11, are sufficiently accurate for estimating purposes. The area and gage size for a stamping is found from part dimensions. The scrap allowance between successive blanks in a strip should be 1/32 in. for stock less than 1/32 in. thick, an amount equal to the stock thickness between 1/32 and 3/16 in., and a maximum of 3/16 in. for greater thicknesses. The scrap allowance on each side of a blank at the edges of a strip is equal to the stock thickness plus the product

TABLE 10.7 CUTOFF TOOL WIDTHS

Depth of cut in inches	*Width of cutoff tool in inches (for steel)*
Up to 3/8	1/16 to 1/8
1/4 to 5/8	5/32
1/2 to 3/4	3/16
5/8 to 1	1/4
3/4 to 1 1/4	5/16
Above 1 1/4	5/16 plus

Note: Overlap provided for requirements of different grades and heat treatment of steel. Cutoff tools for aluminum or soft brass may be about 3/4 as wide as those for steel.

of 0.015 times the diameter or width of blank.

From 1 to 12 per cent of material is normally lost in processing in scrapped pieces, butt ends, droppings, and so forth, depending upon conditions. An average allowance of 5 per cent is commonly made for such bulk losses.

The weight of a piece multiplied by the unit cost of material gives the material cost per piece. If the unit cost covers only the purchase price of the material, the material cost is multiplied by one or more additional factors to account for bulk losses, purchasing, and handling costs. The unit-cost figure frequently is larger than the purchase price and accounts for the other costs, in some cases for a charge for heat treatment. Material unit costs generally decrease for larger amounts of material. Scrap from a few materials, such as brass, has appreciable salvage value, and that may be deducted from the material cost.

Unit material costs need to be checked at intervals, on the average about every six months, and corrected.

11.3 ESTIMATING DIRECT-LABOR COSTS

The total direct labor required to make a part may be estimated by reference to that required on similar jobs. A more refined method is to divide the job into operations, which is the same as prescribing the process.

The basis for estimating operation time is previous performance on similar operations. Some estimators with backgrounds as toolmakers, mechanics, or foremen are able to judge operation time values closely. Much tool estimating and some product estimating are done in this way.

Some estimators have found rules of thumb that give sufficiently accurate and quick estimates of operation times. The time for a weld may be estimated by multiplying the length by an ascertained average time to weld one inch. The cutting time may be calculated for an operation and multiplied by a factor that studies in a particular plant have shown gives the total time for that particular type of operation. Such factors must be used with discretion.

Those without sufficient shop experience may have to refer to records for operation time values. Cost-accounting records may be consulted for specific operations. The estimate sheets of Fig. 10.13 have a column to enter the actual time for each operation after the job has been completed. After a person has worked with such records for a while, he remembers the times of typical operations and needs not refer to the files for every case.

Tables* or charts, prepared to show the time values for particular typical operations performed on various shapes and sizes of pieces of various materials, and with various amounts of stock removal, are helpful for quick and accurate estimating.

When cost accounting or shop records

* Charles Bohmer, and George Dannes, *Die Designing and Estimating* (Cleveland: Huebner Publications, Inc., 1931). George S. Clark, "Post Design Estimating," *The Tool Engineer*, Vol. XXIII, No. 11, November 1949, 27.

are used, care must be taken that the information is reliable. Because of equipment breakdowns, carelessness, or intention, time may not be recorded properly in the shop on some jobs. An operator may be inexperienced, or proper tools may not be available for the first run of an operation.

11.4 BREAKDOWN OF OPERATIONS

Where work methods are standardized, operations can be divided into standard elements. The most accurate estimates of operation time are obtained by evaluating operation elements and adding them together.

The time needed for almost any fabrication operation can be divided into (1) setup time, (2) man or handling time, (3) machine time, and (4) lost or down time.

Machine time differs from the others because it can be calculated. The machine time for an operation is $T = L/F$. The length of cut, L, in inches includes the length of the surface cut plus the distance traveled by the cutter at feed rate in approaching the surface plus the overtravel of the cutter. The feed, F, is expressed in inches per minute. Charts like Fig. 10.14 and special types of slide rules are commonly utilized to ascertain machine time quickly. The unit time in minutes per inch obtained from the chart of Fig. 10.14 is multiplied by the length of cut to obtain the machine or cutting time.

Setup and man time elements are evaluated by time study. Average values are tabulated in convenient ways in many plants for estimating purposes. An example of standard elements for lathe operations is given in Table 10.8. If standards are not available in a particular factory, reference may be made to published tables* of standard elemental times for common operations.†

Setup time is normally applied once to each lot of pieces, but for estimating purposes may be prorated among the pieces in a lot to give a unit setup time. A prorated unit setup cost applies to only one lot size and must be clearly specified as such, so that the figures will not be used for other jobs with erroneous results.

Allowances for personal needs, fatigue, and other justifiable items are added to elements measured by time-study methods. Tables prepared for estimating purposes may show elemental times that include necessary allowances or may show the allowances separately.

Lost or down time resulting from equipment breakdowns, parts that do not fit, tools that do not work properly, defective material, and so forth, are accounted for by a performance factor applied to estimated operation time. Just what the lost time may be for a specific operation cannot be predicted, and the performance factor reflects average losses. It may be derived by dividing the total actual time for all jobs done in a plant over a period of several months to a year by the sum of the times estimated for the same jobs. This factor must be checked from time to time. Studies in various plants have shown performance factors from 1.10 to 1.70.

A performance factor may include corrections for average errors in estimating, such as the items overlooked in making a rough estimate without the benefit of detailed part drawings or the tendency of a particular estimator to be low. The "Estimating Contingency" in Fig. 10.13b is a performance factor.

11.5 ESTIMATING INDIRECT COSTS

Indirect costs are commonly distributed for estimating purposes by rates determined by cost-accounting

* Joseph C. Derse, *Machine Operation Times for Estimators* (New York: The Ronald Press Company, 1946). W. A. Nordhoff, *Machine Shop Estimating* (New York: McGraw-Hill Book Company, Inc., 1947).

† See Section 5, Article 5.4.2, for estimation of direct labor time by means of synthetic time standards.

DIAMETER IN INCHES																					FEED PER REVOLUTION IN THOUSANDTHS											
1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2	2 5/8	2 3/4	2 7/8	3	R P M	002	.004	.007	.010	.015	.020	.025	.031	.046	.060	.090
.13	.16	.20	23	.26	29	33	36	39	43	46	49	52	56	59	62	65	69	72	75	79	1	500	150	143	100	67	50	40	32	22	17.	11.
																					6 9	83 30 55 55	41 65 27 78	23 82 15 89	16 66 11.11	11 16 7 44	8 33 5 56	6 66 4 44	5 23 3 56	3 66 2 44	2 83 1 89	1.83 1.22
																					11 15	41 65 33 30	20 83 16 65	11 91 9 52	8 33 6 66	5 58 4 46	4 17 3 33	3 33 2 66	2 67 2 13	1 83 1.47	1.42 1.13	91 .73
																	17	18	19	20	19 25	26 30 20 00	13 15 10.00	7 52 5 72	5 26 4 00	3 52 2 68	2 63 2 00	2 10 1 60	1 68 1 25	1 16 88	89 66	.58 .44
									17	19	20	16 21	17 23	18 24	19 25	20 27	21 28	22 30	23 31	24 32	31 41	16 10 12 15	8 05 6 00	4 60 3 47	3 22 2 43	2 16 1 63	1 61 1 22	1 29 .97	1 04 78	70 53	.53 .41	.36 .27
				18	20	15 22	19 24	20 27	22 29	24 31	26 33	27 35	29 38	31 40	32 42	34 45	36 47	37 49	39 51	41 53	52 68	9 60 7 35	4 80 3 68	2 75 2 10	1 92 1 47	1 29 98	96 74	77 59	61 47	42 32	32 25	21 16
	17	18 22	19 25	22 29	25 32	27 36	30 40	33 43	36 47	38 50	41 54	44 58	47 61	49 65	52 68	55 72	58 76	60 79	63 83	66 86	84 110	5 95 4 55	. 98 2 28	1.70 1 30	1 19 91	80 61	60 46	48 36	38 29	26 20	20 15	13 10
18	20 23	25 27	29 32	33 37	37 41	41 46	45 50	49 55	53 60	57 64	61 68	65 73	70 78	74 82	78 87	82 92	86 96	90 101	94 105	98 110	125 140	4 00 3 55	2 00 1 78	1 14 1 02	80 71	54 48	40 36	32 28	26 23	18 16	14 12	09 08
21 24	26 29	31 35	37 41	42 47	47 53	52 59	58 65	63 71	68 77	73 82	78 88	84 94	89 100	94 106	99 112	105 118	110 123	115 130	120 135	126 141	160 180	3 15 2 75	1 58 1 38	90 79	63 55	42 37	32 28	25 22	20 18	14 12	11 09	07 06
26 29	33 37	39 44	46 52	52 59	59 66	65 74	72 81	79 88	85 96	92 103	98 110	105 118	111 125	118 133	124 140	131 147	137 155	144 162	150 169	157 177	200 225	2 50 2.20	1 25 1 10	72 63	50 44	34 .29	25 22	20 18	.16 14	11 10	.08 07	05 .05
33 38	41 46	49 57	57 67	65 76	74 86	82 96	90 105	98 115	106 124	115 134	123 143	131 153	139 162	147 172	155 182	164 191	172 201	180 210	188 220	196 229	250 292	2 00 1.70	1 00 85	57 49	40 34	27 23	.20 17	16 14	13 11	09 07	07 06	04 .04
43 49	54 61	65 74	76 86	86 98	97 110	108 123	119 135	130 147	140 160	151 172	162 184	173 196	184 209	194 221	205 233	216 245	227 258	238 270	248 282	259 295	330 375	1 50 1.30	75 65	.43 37	.30 26	20 17	.15 13	.12 10	.10 08	07 06	05 04	.03 03
56 64	70 80	83 96	97 112	111 127	125 143	139 159	153 175	167 191	181 207	195 223	209 239	223 255	236 271	250 287	264 303	278 319	292 335	306 351	320 367	334 382	425 487	1 15 1 00	58 50	33 29	.23 .20	15 13	11 10	09 08	07 06	.05 04	04 03	03 .02
72 82	90 102	108 123	126 143	144 164	162 184	180 205	198 225	216 245	234 266	252 286	270 307	288 327	306 348	324 368	342 389	360 409	378 430	396 450	414 470	432 491	550 625	.90 80	45 40	26 23	.18 16	12 10	.09 08	.07 06	06 05	04 .04	03 03	02 .02
91 104	112 128	140 160	161 184	182 208	203 232	231 264	252 288	273 312	301 344	322 368	343 392	364 416	392 448	413 472	434 496	455 520	483 552	504	525	553	700 800	71 .62	36 31	20 18	14 .12	.09 08	07 06	.06 05	05 04	03 03	02 02	01 01
117 130	144 160	180 200	207 230	234 260	261 290	297 330	324 360	351 390	387 430	414 460	441 490	468 520	504	531	558						900 1000	55 50	.28 25	16 14	11 10	07 07	05 05	04 04	03 03	02 02	02 .02	.01 01
143 156	176 192	220 240	253 276	286 312	319 348	363 396	396 432	429 468	473 516	506	539										1100 1200	45 42	.23 21	13 12	09 08	.06 05	04 04	04 03	03 03	02 02	.01 01	01 009
169 182	208 224	250 280	299 322	338 364	377 406	429 462	468 504	507 546	559												1300 1400	38 36	.19 .18	.11 .10	08 07	06 05	04 .03	.03 02	.02 02	.02 01	01 01	.008 008
195	240	300	345	390	435	495	540														1500	33	16	09	07	04	03	02	02	01	01	007
PERIPHERAL SPEED IN FEET PER MINUTE																					TIME IN MINUTES PER INCH											

FIG. 10.14 CHART FOR QUICKLY COMPUTING TIME IN TURNING.

TABLE **10.8** HANDLING TIME ELEMENTS FOR TURNING*

Avg. diam. in inches	Rechuck or place between centers—Length in inches													
	2	4	6	8	10	12	14	16	18	20	24	28	32	36
	Time in minutes													
¾	.10	.10	.10	.10	.10	.12	.14	.14	.16	.16	.18	.18	.20	.20
1	.10	.11	.12	.15	.18	.21	.24	.25	.28	.29	.32	.33	.36	.37
1¼	.14	.16	.18	.22	.26	.30	.34	.36	.40	.42	.46	.48	.52	.54
1½	.18	.21	.24	.29	.34	.39	.44	.47	.52	.55	.60	.63	.68	.71
2	.22	.26	.30	.36	.42	.48	.54	.58	.64	.68	.74	.78	.84	.88
2¼	.26	.31	.36	.43	.50	.57	.64	.69	.76	.81	.88	.93	1.00	1.05
2½	.30	.36	.42	.50	.58	.66	.74	.80	.88	.94	1.02	1.08	1.16	1.22
2¾	.34	.41	.48	.57	.66	.75	.84	.91	1.00	1.07	1.16	1.23	1.32	1.39
3	.38	.46	.54	.64	.74	.84	.94	1.02	1.12	1.20	1.30	1.38	1.48	1.56
3½	.42	.51	.60	.71	.82	.93	1.04	1.13	1.24	1.33	1.44	1.53	1.64	1.73
4	.44	.56	.66	.78	.90	1.02	1.14	1.24	1.36	1.46	1.58	1.68	1.80	1.90
4½	.48	.61	.72	.85	.98	1.11	1.24	1.35	1.48	1.59	1.72	1.83	1.96	2.07

TABLE **10.8** (*Continued*)

	Place and Remove - Hand - Electric - Air - 3- or 4-jaw chuck—Length in inches								
	2	4	6	8	10	12	14	16	18
	Time in minutes								
5	.52	.66	.80	.94	1.08	1.22	1.36	1.50	1.64
5½	.56	.71	.86	1.01	1.16	1.31	1.46	1.61	1.76
6	.60	.76	.92	1.08	1.24	1.40	1.56	1.72	1.88
6½	.64	.81	.98	1.15	1.32	1.49	1.66	1.83	2.00
7	.68	.86	1.04	1.22	1.40	1.58	1.76	1.94	2.12
7½	.72	.91	1.10	1.29	1.48	1.67	1.86	2.05	2.24
8	.76	.96	1.16	1.36	1.56	1.76	1.96	2.16	2.36
8½	.80	1.01	1.22	1.43	1.64	1.85	2.06	2.27	2.48
9	.84	1.06	1.28	1.50	1.72	1.94	2.16	2.38	2.60
9½	.88	1.11	1.34	1.57	1.80	2.03	2.26	2.49	2.72
10	.92	1.16	1.40	1.64	1.88	2.12	2.36	2.60	2.84
10½	.96	1.21	1.46	1.71	1.96	2.21	2.46	2.71	2.96
11	1.00	1.26	1.52	1.78	2.04	2.30	2.56	2.82	3.06
11½	1.04	1.31	1.58	1.85	2.12	2.39	2.66	2.93	3.18
12	1.08	1.36	1.64	1.92	2.20	2.48	2.76	3.04	3.30
13	1.12	1.41	1.70	1.99	2.28	2.57	2.86	3.15	3.42
14	1.16	1.46	1.76	2.06	2.36	2.66	2.96	3.26	3.54
15	1.20	1.51	1.82	2.13	2.44	2.75	3.06	3.37	3.66
16	1.24	1.56	1.88	2.20	2.52	2.84	3.16	3.48	3.78
17	1.28	1.61	1.94	2.27	2.60	2.93	3.26	3.59	3.90
18	1.32	1.66	2.00	2.34	2.68	3.02	3.36	3.70	4.02
19	1.36	1.71	2.06	2.41	2.76	3.11	3.46	3.81	
20	1.40	1.76	2.12	2.48	2.84	3.20	3.56	3.92	
21	1.44	1.81	2.18	2.55	2.92	3.29	3.66	4.03	
22	1.48	1.86	2.24	2.62	3.00	3.38	3.76		
23	1.52	1.91	2.30	2.69	3.08	3.47	3.86		
24	1.56	1.96	2.36	2.76	3.16	3.56	3.96		
Over	1.60	2.01	2.40	2.83	3.24	3.65	4.06		

Use Place & Remove Time & Factor	Factor
Face Plate and Centers with Dog	.8
Face Plate and Centers with Driver	.7
Chuck and Center	1.2
Chuck and Steady Rest	1.5
Chuck and Steady Rest and Center	1.7
Air Arbor—Thread or Stud	1.0
	Min.
Pcs. On and Off Thread Arbor—Long	.50
Tighten & Loosen Headstock Center	.20
Split Bushings use in P. & R.—Add	.05
Minimum Time to P. & R. Work Between Centers	.20
Arbor Press In & Out, Add to P. & R.	.30
Pcs. In & Out of Fixtures—On or Off Table—Small	.15
Medium	.30
Large	.50
Extra Large	.80
Tighten Nut and Bolt	.20
Tighten Clamp 1 Nut or Bolt	.25
Tighten Clamp 2 Nut or Bolt	.40
Clamp On & Off 1 Nut or Bolt	.50
Clamp On & Off 2 Nut or Bolt	.70
Jack Moved to P. & R. Piece	.60
Clean Chips Off Job	.30
Adjust Set Screw	.10
Place & Remove Shim in Fixture	.05
Nut Arbor—Add to P. & R.	.50

Add one (1) minute for hoist on piece over 35 pounds. (lbs. = $D^2 \times$ length $\times$ .22)—Solid piece.

Double above times for Independent 4-Jaw Chuck—Includes ordinary indicating.

Tubing or like pieces—Factor .5

TABLE **10.8** (*Continued*)

Tool Adjust—Measuring—Special allowances										
Short Operations by Stock Diameter	¾″	1¼″	2″	3″	4″	5″	7″	10″	15″	Over
Spot Drill or Center	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55
Chamfer—Bevel—Radius—Neck—Recess	.05	.10	.15	.20	.25	.30	.35	.40	.60	.80
Use these Material Factors with above operations, SAE 1020, 1112, Cast Iron, Brass - 1.00—Machine Steel, Bronze, Tubing - 1.50—Tool Steel - 2.00										
Measuring Times by Outside-Inside Diameters or Lengths	½″	1″	2″	3″	4″	5″	7″	10″	15″	Over
Scale Short Length by O. D.	.10	.10	.15	.15	.15	.20	.20	.25	.30	.35
Scale Long Length (over 4 feet) by O. D.	.35	.35	.40	.40	.50	.50	.60	.70	.80	.90
V-Gauge—Calipers by O. D.	.20	.25	.25	.25	.30	.30	.40	.50	.60	.70
Thread Gauge Male by I. D. Female by O. D.	.10	.15	.20	.25	.35	.45	.65			
Plug Gauge by I. D.	.05	.05	.10	.20	.30	.30	.40	.50	.60	.70
Taper Gauge Male by I. D. Female by O. D.	.20	.25	.30	.35	.40	.45	.50	.60	.70	.80
Bevel Protractor	.20	.20	.20	.30	.30	.30	.40	.50	.60	.70
Depth Micrometers by Length of Depth	.15	.20	.25	.30	.35	.40				
Micrometers and Verniers (X2 on inside mikes)	.05	.10	.15	.20	.25	.30	.40	.50	.75	1.00
Height Gauge	.10	.10	.15	.15	.20	.20	.25	.25	.30	.30
Tool Adjust By Stock Diameters	¾″	1¼″	2″	3″	4″	5″	7″	10″	15″	Over
Hexagon Turret or Cross Slide	.10	.15	.17	.20	.25	.27	.30	.35	.40	.45
Tailstock (Hole Diameter)	.20	.30	.40	.50	.60					
Tool Adjust on Work Supported on Both Ends—By Length	6″	12″	18″	24″	30″	36″	48″	60″	72″	Over
Cross Slide	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55

* Courtesy the Monarch Machine Tool Company.

methods. The number of hours of direct labor estimated for a job is generally multiplied by a rate to account for factory overhead. Often a single factor is used, including both the direct-labor and overhead rates. For most tool estimating and for some product estimating, one overhead rate is applied to all operations in an estimate. However, to reflect difference in methods and equipment, overhead should be broken down to an extent corresponding to the detail to which direct costs are estimated, as indicated in Fig. 10.12. Thus, different overhead rates may be used to estimate costs for different departments, work centers, or types of operations in a plant.

As a rule, general administrative and selling costs are charged in proportion to the number of dollars of total manufacturing cost. This may be done by a separate factor, or the charges may be included with direct labor and factory overhead in one rate, as in the example of Fig. 10.13. In that case, the $6.10 per hour rate against production unit time covers direct labor, factory overhead, general overhead and marketing costs, and expected profit. However, general overhead is not always related to factory overhead. The space designated "Plus Marketing and Profit Ratio" in Fig. 10.13 is used to enter general overhead, marketing costs, and profit against outside labor which is not charged with factory overhead and against which the $6.10 rate is not applicable.

Standard purchased parts and material are not generally required to carry factory and general overhead, although practice in this respect is not uniform. A large markup puts such merchandise in a poor competitive position, but charges for out-of-pocket expenses for shipping, purchasing, and handling are justifiable.

An overhead rate based upon the practical capacity of a plant may be desirable from the accountant's standpoint, to establish standard costs. The estimator needs a more realistic rate based upon an actual current or anticipated level of activity to forecast costs as they are likely to be. The estimator must understand the principles of the cost-accounting system that furnishes him information to determine the relevancy and adequacy of the data. The estimator must be careful not to duplicate items by estimating them individually if they are already included in the overhead rates furnished by the cost accountant.

When costs are estimated to set a selling or contract price, two figures may be helpful, especially as terminal points for negotiating the price. The first is an estimate of costs directly attributable to the project, including material, labor, and other direct costs plus that part of overhead that varies with the activity and that will be incurred only if the job is undertaken. The second figure is the sum of the first plus the proportion of fixed costs that do not depend on the specific job but toward which the job should contribute as much as possible.

11.6 ESTIMATING THE COSTS OF AUXILIARY SERVICES

As a rule, most of the auxiliary services of production are included in overhead for estimating purposes. However, when such items are sizable and do not vary in proportion to direct manufacturing costs, it is preferable to estimate them individually. For instance, the cost of entering and following up an order may be the same for a small as for a large order. Engineering development and design may involve only slight modifications for one job but may be quite extensive for another.

Services that involve creative work or the solution of unforeseeable problems are not amenable to standardization. The amount of time to design a mechanical device may be estimated on the basis of what has been found necessary for a similar job or on the basis of how much time the designer thinks he will need. Whenever a sizable amount is at stake, it is always well for an estimator to seek the opinions of those who will have to fulfill the estimate in performance.

The time estimated for a service such as engineering is multiplied by an hourly

rate to obtain the cost of the service. If several grades of designers, draftsmen, or other workers are employed on a job, the rate may be different for the time expended by each group. The hourly rate covers direct labor and also charges for administration, selling, supervision, housing, light, heat, and so forth.

11.7 ESTIMATING COSTS FOR THE FUTURE

Current costs for labor, material, and overhead are usually safe for an estimate that will materialize in a few days or weeks. On the other hand, estimating may be quite hazardous when costs are to be incurred and returns are to be realized after a lapse of months or years, such as after a period of designing, planning, and so on. Present costs and quotations must serve as a start in preparing estimates for the future, but they may have to be modified. An estimator must be in touch with economic trends, or must seek advice from someone who is, to estimate costs and prices far in advance.

Not only future prices, but also anticipated volume and facilities, must be studied. Unit fixed and overhead costs tend to increase as volume decreases, and vice versa. Also a higher output may permit the utilization of improved equipment and work methods. New products may absorb some of the overhead costs of a plant.

11.8 THE COSTS OF COST ESTIMATING

Every estimator knows that some of his estimates are high, others are low, some are close, and a few are far from true costs. If estimating is done conscientiously and competently, errors arise from the chance effects of many factors that cannot be investigated fully without unreasonable expense. Accuracy is improved by breaking a project into elements because small items can be estimated more precisely than large ones and the errors in estimating the individual elements tend to offset each other. The best situation prevails when a project is broken down into elements of approximately equal size.

Although the costs estimated for jobs over a period of time may be on the average close to the true costs of the jobs, the error in each job represents a real or potential loss. A job that is estimated low results in a real loss. A job that is high is in a poor competitive position. The discrepancies in all jobs may be reduced by breaking the jobs into more elements, but that increases the cost of making the estimates. The most economical number of elements for any project is that number that results in the lowest total cost.

11.9 THE PROPER NUMBER OF ELEMENTS IN AN ESTIMATE

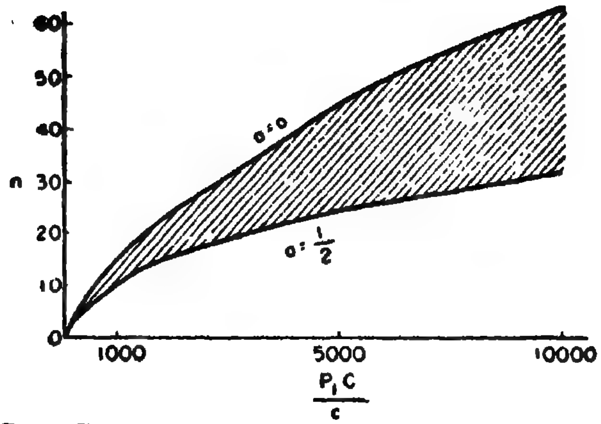
The theoretical number of elements into which a project should be divided for the lowest total cost is*

$$n_m = b\left(\frac{P_1C}{c}\right)^q$$

when P_1 is the spread distribution of percentage errors in estimating the particular type of project on an over-all basis, C is the value of the project or the amount at stake in dollars, c is the cost of estimating each element, and b and q depend upon the estimating system. The factor b is usually less than ½ and the exponent q less than 1. This relationship indicates that total estimating cost is near the minimum over a large range of numbers of elements around n_m. That means that a uniform estimating procedure is economical for all projects of any particular type in a plant.

The theoretical numbers of elements desirable for estimating projects of various characteristics are indicated by points in the shaded zone of Fig. 10.15. A project several times as large as an-

* L. E. Doyle, "An Analysis of Cost Estimating Principles and Practices," Paper T-9, American Society of Tool Engineers, 1952.



Paper T9-1, 1952, The American Society of Tool Engineers.

FIG. 10.15 THE THEORETICAL OPTIMUM NUMBER OF ELEMENTS FOR ESTIMATING THE COST OF A PROJECT.

other requires less than a proportionately larger number of elements.

12. TOOL DESIGN

A *tool* is a device for working or cutting a material into a desired shape, for holding workpieces, or for measuring parts after work has been completed. This definition embraces implements used in all industries, but tool engineering is generally concerned with the tools of the metal-working industries. These are machine tools and accessories, cutting tools, fixtures, jigs, dies, and gages. Also recognized as tools are such adjuncts as collets, sleeves, and toolholders.

Machine tools are machines capable of reproducing themselves or other machines. The basic machine tools are the lathe, milling machine, drill press, planer, and shaper. Others, such as the turret lathe, boring mill, and grinders are modifications of the basic types. The design and construction of machine tools is a specialized industry, but tool engineers throughout the metal-working industries are engaged in designing and modifying attachments and the other tools that augment and supplement machine tools.

12.1 CLASSES OF TOOLS

Tools differ in quality and consequently in cost. A durable, accurate, and rapid-acting but expensive tool is economical for producing a large number of parts. A relatively cheap tool is adequate for few parts. In this respect, tools may be classified as follows:

Class I or *A* tools are of the highest quality to produce large quantities of precision products, generally in excess of 10,000 pieces. They must have long lives, be accurate throughout their lives, be easy to maintain, and be able to produce at a high rate. They are the most expensive to build. All details subject to wear are made of hard, wear-resistant materials and are readily replaceable, as are also any necessarily fragile details. The main members of such tools are heavy and rugged. Provision is made for easy chip removal and for application of adequate cooling and lubricating fluid. Mechanisms must be quick-acting, often automatic, and foolproof. Dies are designed in progressive, combination, or compound forms to minimize work handling. Molds are made with multiple cavities, knockouts, and chrome plating for long life and are adaptable to semiautomatic and transfer presses. Cutting tools are usually cemented carbide types.

Casting patterns with aluminum matchplates and multiple prints and metal core boxes and dryers are used.

Class II or *B* tools are designed to produce interchangeable products but in medium quantities, a few thousand or so. They are simple, made of cheaper materials, have lighter members, cost less than Class I tools, and are made to last only long enough to produce definite quantities of parts. Mechanisms are simple, slow-acting, and require operator attention. For this class, several simple dies would be built instead of one complex die, but they would be steel dies of conventional construction. Single- and double-cavity molds are used on hand presses. Many cutting tools in this class, especially form tools, are of high-speed steel.

Class III or *C* tools are the cheapest that can be used for low production, a few hundred to a few thousand pieces, without excessive operating cost. They are simple, rarely combine operations, and require skilled operators. Wear plates, blocks, and so forth, may be provided but are seldom hardened Standard measuring instruments are preferred to gages. Conventional machine tools with standard attachments and accessories are used. Continental-type dies are characteristic of this class. For castings, aluminum matchplates but wooden patterns and core boxes are common.

Class IV, *D*, or *temporary* tools are made to produce only a very few parts, often on an experimental basis. They are the lowest-cost tools that will do a job at all. Standard holding devices, cutting tools, and basic machine tools are used almost entirely. Where a chuck or vise is not suitable, the work is clamped to the machine table. Dies frequently are not made for this class of work, but, where used, they are often made from soft metal or nonmetallic materials, and pieces may have to be finished by extra operations. Wood patterns are the rule.

If the cost of a Class I tool is represented by 4, then the approximate cost of a Class II tool is 3, a Class III tool is 2, and a Class IV tool is 1.

12.2 TOOL DESIGN PROCEDURES

A process plan informs the tool designer what a tool must do, under what conditions it must operate, and the type of tool required. The designer must select the necessary details and arrange and proportion the device to perform the required task efficiently.

By the "project method" of tool design, found in small plants, one designer is assigned to designing all the tools for one part. By the "group method," each designer specializes in a particular type of tool, such as jigs, fixtures, or dies. In large plants, a method having the advantages of both these methods has each project directed by a senior designer or group leader with assistants who specialize.

12.3 TOOL DRAWINGS

The first sheet of a set of drawings shows the assembly or layout of the tool. An example of a layout drawing is shown in Fig. 10.23. The workpiece is drawn in phantom, commonly in red, in its proper position with respect to the tool during the operation. As many views are given as are necessary for clarity. Three views are conventional for a die: a plan view of the lower member, a plan view of the upper member (sometimes turned upside down), and a front elevation of both members in working position, often wholly or partially sectioned. Small auxiliary sections are included where helpful.

A stock list on the layout sheet specifies the detail number, number required, description or stock size, and material or specification for each detail. The layout carries assembly dimensions and general notes for the guidance of the toolmaker. In the case of a die, this may include the shut height of the die, diameter of shank, sizes and locations of holes for bolting the die to the press, and size, type, and stroke of press. To save time, small details may not be shown when they occur more than once on a tool lay-

out. For instance, if several identical screws are required, only one may be drawn completely, and the positions of the others may be merely indicated by center lines.

12.4 TOOL DRAWING DIMENSIONS

If a tool has only one or two details, they may be dimensioned on the layout, but usually detailing only clutters the layout and is not satisfactory. As a rule, the details are identified by numbers on the layout sheet and drawn separately and dimensioned on other sheets.

Tool dimensions that are related to the workpiece, machine, or other tools should have tolerances. For instance, the diameter of an arbor or locating plug on which a workpiece must fit must be given a definite tolerance. However, interchangeability of tool details is seldom advantageous, and the dimensions of mating details within a tool may not have tolerances specified, depending upon the system for making the tools. By one system, practically all the work on a single tool is done by a skilled toolmaker or small group, who can be depended upon to get the best results from the means available. For instance, a tolerance is not assigned to the diameter of a plug press fitted into a hole under such conditions, but the nominal diameter and a note calling for a press fit are specified. The toolmaker reams the hole and grinds the plug to fit. A second system of toolmaking employs specialists for the machining operations assigned to them by a toolmaker who assembles the details. The specialists are not aware of the specific purposes of the details they make, and detail drawings for their use should have tolerances specified on all dimensions.

13. CUTTING TOOLS

13.1 CUTTING-TOOL MATERIALS

Carbon tool steel contains from 0.90 to 1.20 per cent carbon and very little alloying elements. It is hard, and wear-resistant at low temperatures, takes a keen edge but softens at temperatures above 400° F, and is limited to slow speeds and light work. Carbon tool steel is not used for production, but it is cheap and easy to fabricate and harden. It is made into special tools, like odd sizes of drills that are infrequently and lightly used, without too much investment.

High-speed steel is highly alloyed and is made in many analyses and brands. One of the commonest types, known as 18-4-1, contains about 0.55 to 0.75 per cent carbon, 18 per cent tungsten, 4 per cent chromium, and 1 per cent vanadium. Molybdenum may mostly or wholly supplant the tungsten, as in a widely used "Moly" high-speed steel that contains 8 per cent molybdenum, 4 per cent chromium, 1½ per cent tungsten, and 1 per cent vanadium. Cobalt is added to some high-speed steels to improve red hardness.

High-speed steel loses its hardness at red heat—i.e., above 1100° F—and is capable of only moderate speeds. It is tough and can be fabricated and ground into many forms fairly easily but requires care in heat treatment. Its cost is moderate.

Cast nonferrous alloys contain no iron, cannot be softened for machining, and must be cast to shape and ground to size. A typical alloy may contain from 43 to 48 per cent cobalt, 17 to 19 per cent tungsten, 30 to 35 per cent chromium, and about 2 per cent carbon. Variations within the ranges produce various combinations of hardness and toughness for different purposes. These alloys retain hardness and become tougher at red heat. They have a hard skin that stands the abrasive action of cast iron, malleable iron, and bronze.

Cemented carbides, carbides, or *sintered carbides* are composed of hard particles of tungsten carbide, commonly mixed with tantalum and titanium carbides to improve resistance to abrasion and to lower the coefficient of friction and held together by a binder of cobalt or nickel. The ingredients are mixed together in powdered form, compressed in a mold, presintered, and cut to desired

shapes. The blanks are sintered at high temperatures and finished by grinding.

Cemented carbides are expensive but stand up under high speeds and temperatures, are hard but relatively brittle, remove metal rapidly, give good finishes, and are economical for machining parts in large quantities. Various grades are made by varying the proportions of the ingredients to suit different uses. At one extreme are the hardest, but most brittle, carbides with high resistance to abrasion and wear. In other grades, hardness is sacrificed in various degrees for strength and shock resistance.

Diamond is the hardest known material, can be run at speeds up to 5000 s.f.p.m., cuts hard material, and produces fine finishes but is expensive, brittle, a poor heat conductor, and limited to light cuts. A typical application is the precision boring of holes. (See Fig. 9.8, p. 647, for diamond dressing tools.)

As reported by Boston, the approximate relative tool lives under comparable conditions are 30 to 50 per cent for carbon tool steel, 100 per cent for high-speed steel, 150 to 200 per cent for cast nonferrous alloy, and 300 to 1000 per cent for cemented carbides.

FIG. 10.16 THE ELEMENTS AND ANGLES OF A SINGLE POINT TIPPED TOOL.

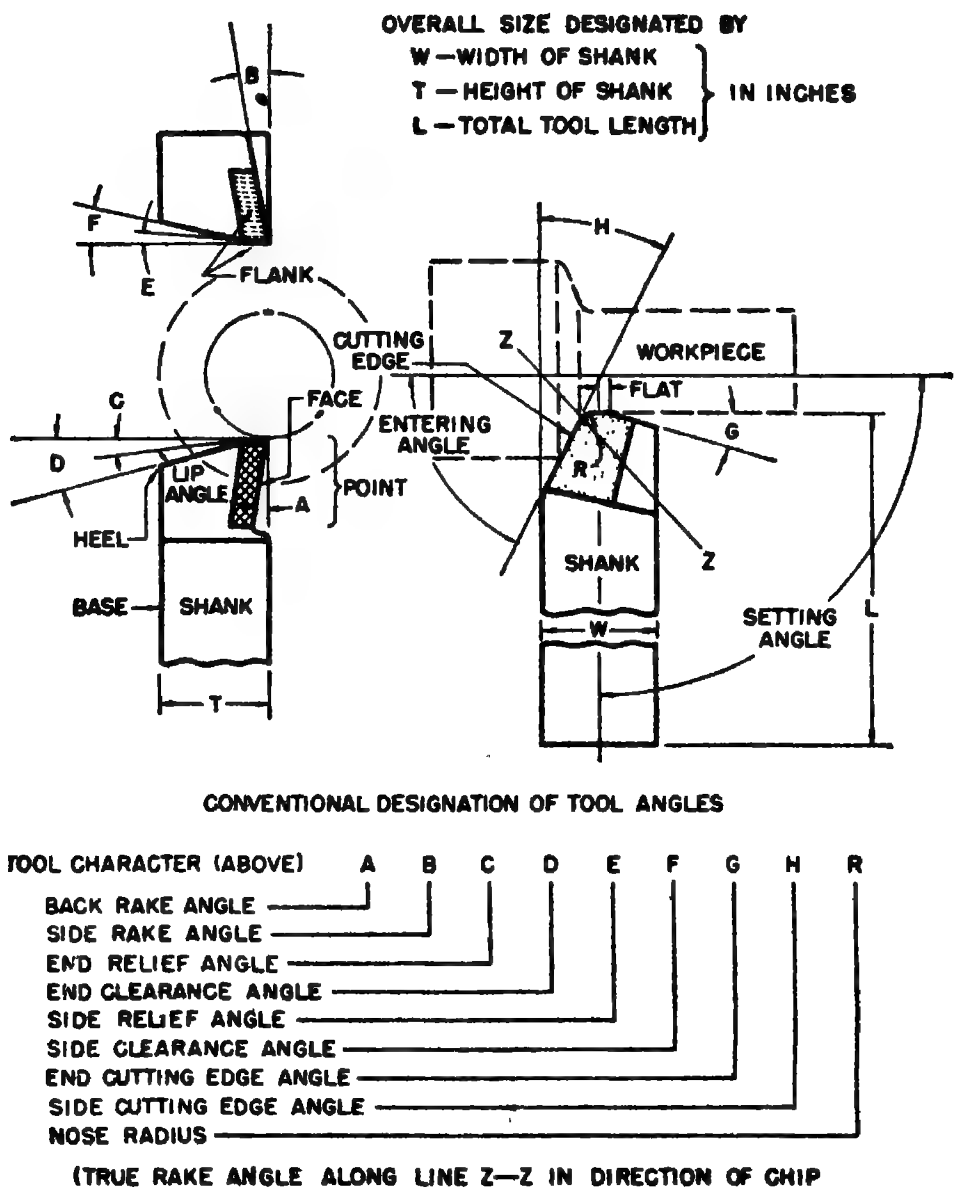


TABLE **10.9** RAKE ANGLES FOR SINGLE POINT TOOLS

Rake Angle Normal to Cutting Edge in Degrees

	Tool Material					
	High-speed steel		*Nonferrous alloys*		*Cemented carbides*	
Work material	*Back rake*	*Side rake*	*Back rake*	*Side rake*	*Back rake*	*Side rake*
Aluminum	15	35			10-20	10-20
Brass	0	5-(−4)			0	4-14
Cast Iron	5-8	12-20	0	4-6	0-4	0-4
Steel, Soft	8-14	18-22	0	10-20	0	10-20
Steel, Medium	8	12-18			0	3-10
Steel, Hard	5	8-12			0	0-5

13.2 ELEMENTS AND ANGLES OF CUTTING TOOLS

The elements, angles, and standard sizes of single-point tools are defined in the American Standard *ASA B5.22-1950, Single Point Tools and Tool Posts*. The chief elements and angles are depicted in Fig. 10.16, together with the conventional ways of specifying the size and angles of a tool.

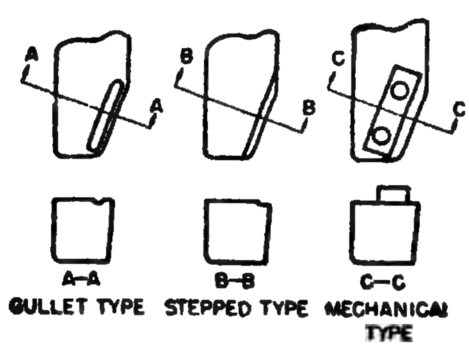
Rake makes a tool cut easier but takes metal from behind and weakens the cutting edge. A practical rake angle, like those indicated in Table 10.9, is a compromise between easier cutting and longer tool life. In general, a small rake angle is desirable for cutting hard materials. Brass is an exception, because a tool with a large rake angle tends to dig into it. If a tool is set other than "on center," its angles must be modified to give the proper effect in the particular position.

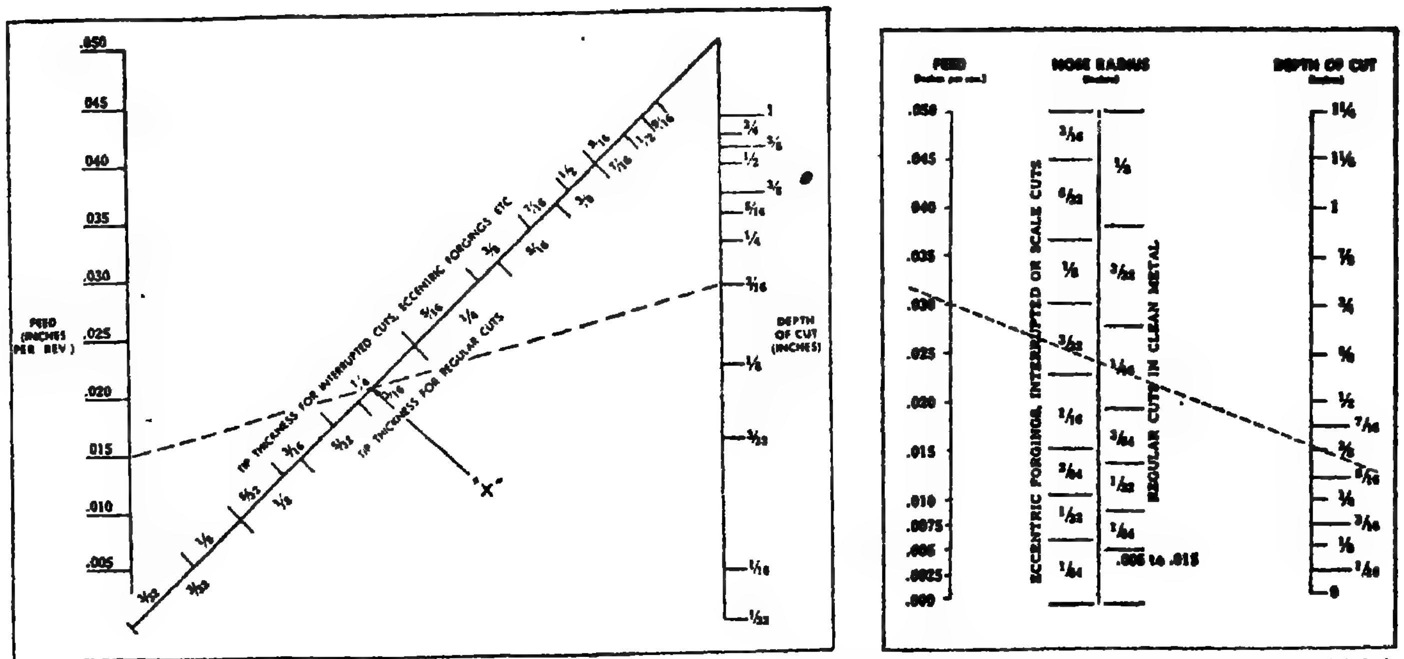
The side rake angle helps to direct the chip away from the tool holder, reduces side deflection of the tool, reduces feeding force, and weakens the tool less than the back rake angle.

Negative rake angles that slope upward from the cutting edge have been found to give good results with carbide tools under certain conditions, such as where the tools are subjected to shocks from interrupted cuts. A tool with a negative rake angle receives impact behind the cutting edge and has extra material backing up its edge. A negative rake angle increases cutting forces at low speeds, but forces drop off at the high speeds possible with carbides; negative rake angles are usually from 2° to 10°, with the other rake angle on the tool positive and 2° to 5° greater in magnitude.

A *relief angle* keeps the tool from rubbing on the work but takes some support from below the cutting edge. For turning, side relief must be greater than the helix angle of the cut and usually is larger than end relief. Relief angles between 5° and 12° are usually ground on lathe tools. The larger angles are suitable for soft materials like aluminum. Brittle

FIG. **10.17** THREE COMMON TYPES OF CHIP BREAKERS.





Courtesy of the Carboloy Department of General Electric Co.

FIG. **10.18** CHARTS FOR DETERMINING THE TIP THICKNESS AND NOSE RADIUS OF A TOOL.

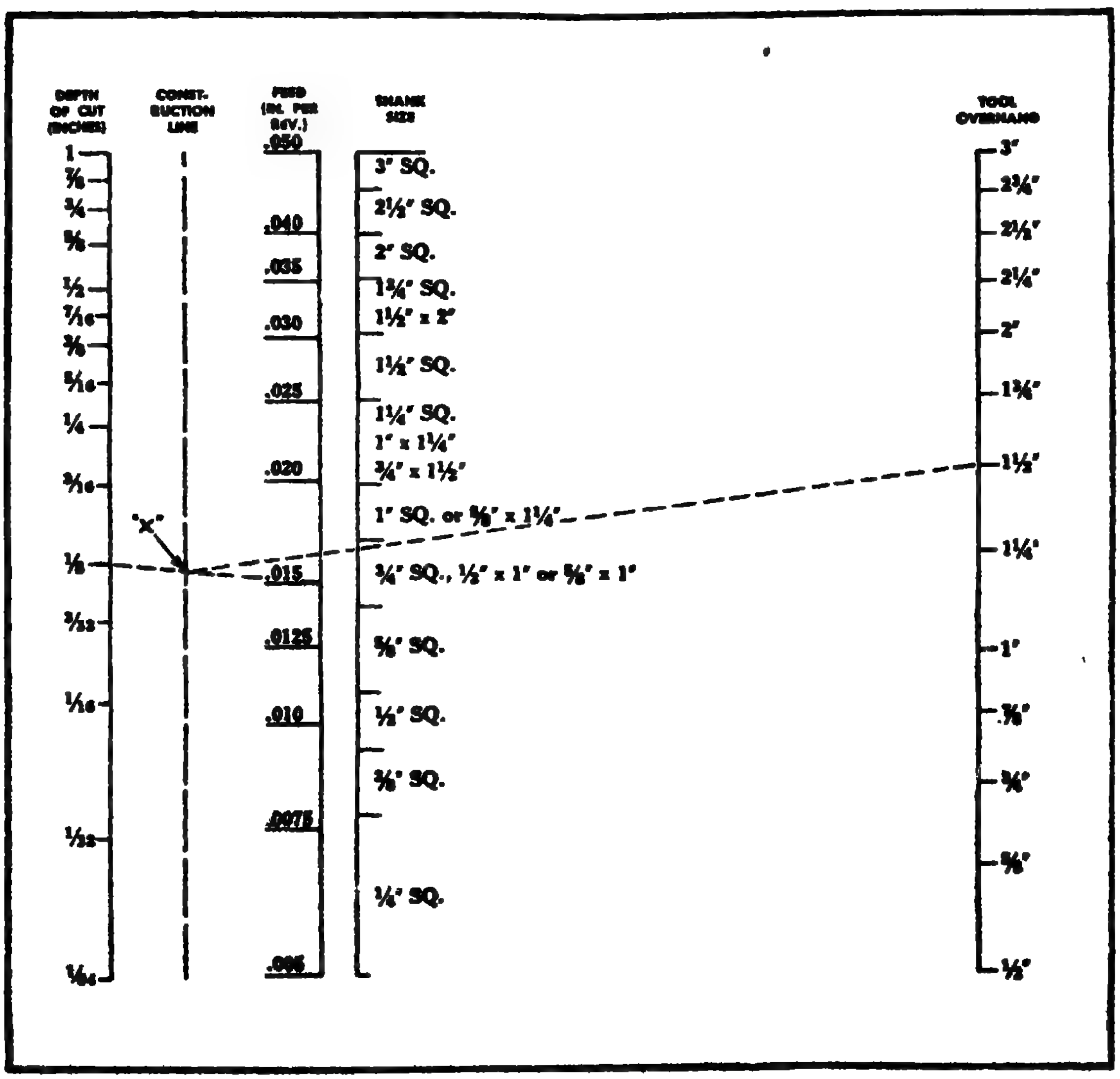
cutting edges of carbide need support and usually have small relief angles. Shaper or planer tools are subject to shock and may have relief angles as small as 4°. The tip on a tool usually overhangs the shank, with a secondary relief or clearance angle from 2° to 5° larger than the relief angle to make the tool easy to grind.

An *end cutting edge angle* reduces drag on the front of the tool that tends to cause chatter. In most cases, 8° to 15° are sufficient behind a flat 1/16 to 5/16 in. long adjoining the nose radius for wiping action. Cutoff and other end cutting tools have no end cutting edge angles.

A *side cutting edge* or *lead angle* increases tool life because it permits initial contact behind the tip when a tool enters a cut, gradual emergence from a cut, and an increased length of cutting edge in action. This angle is usually 5° to 20°, but sometimes is as high as 30° to 40°. Too large an angle promotes chatter. No side cutting edge angle is desirable for cutting a forging or casting with a hard skin, under which the tool should get to crumble the hard material, or for cutting up to a square shoulder. The actual effect of the side cutting edge angle depends upon the setting angle.

A *nose radius* increases tool life, but too much radius promotes chatter. De-

FIG. 10.19 A CHART FOR DETERMINING SAFE SHANK SIZES FOR A TIPPED TOOL.



Courtesy of the Carboloy Department of General Electric Co.

sirable amounts of nose radius are indicated by the nomograph of Fig. 10.18, p. 695.

13.3 CHIP BREAKERS

Chip breakers are means for breaking up troublesome long chips. The gullet type of Fig. 10.17 is a groove 0.015 to 0.030 in. deep with a land 0.015 to 0.030 in. wide behind the cutting edge and is for a tool with a large nose radius. The stepped-type chip breaker has a step 0.015 to 0.030 in. high ground into the face of the tool. The width of a chip breaker should be increased for larger cuts and may range from 1/16 in. for a depth of cut of 1/32 in. and a feed of 0.010 in. per revolution to ¼ in. for a depth of cut of ¾ in. and a feed of 0.032 in. per revolution. The mechanical type of chip breaker is a block fastened to the face of the tool.

13.4 TOOL PROPORTIONS

The chart of Fig. 10.18 specifies proper tip thickness for cutting steel or alloy irons. Thinner tips are suitable for softer materials, and thicker tips for very tough materials. A line is drawn between the desired operating feed and speed on the side scales to intersect the diagonal line from which the proper chip thickness is read from the applicable scale.

The chart of Fig. 10.19 is derived from both theoretical and practical considerations for determining the safe shank size of a tipped tool. In the example, a line is drawn between a desired depth of cut of ⅛ in. and a feed of 0.015 in. per revolution. Another line is drawn from the point of intersection on the construction line to the point representing 1½ in. overhang on the right-hand scale. Its intersection with the shank-size scale designates a ⅝ in. by 1 in. shank size. Tool overhang should be kept as small as possible.

13.5 TYPES OF SINGLE-POINT CUTTING TOOLS

A *solid tool* has the full section of its cutting end made of the cutting material. The shank may be of the same material as the end or may be of soft steel welded to the end. A *tipped tool* has a small piece or tip of cutting material attached to the end on top of the soft shank by brazing, welding, or clamping. A *tool bit* is a relatively small cutting tool clamped in a *toolholder*, and the assembly is called a *bit tool*. A *radial tool* acts with the axis of its shank substantially in a radial position with respect to the work, as in Fig. 10.16. A *tangential tool* is held with its shank substantially tangent to the work surface. A *roughing tool* is designed to remove large amounts of stock with a maximum tool life and for that purpose may have negative rake, a large side cutting edge angle, or a rounded nose, as required. A *finishing tool* has a keen edge, usually with more rake than a roughing tool. The keen edge and greater rake produce a good finish, and often the tool has a specific shape to suit a given job.

Common shapes of cutting tools are depicted in Fig. 10.20. A *recessing tool* is like a boring tool, but is designed to be fed in radially, to undercut a form within a hole. A *knurling tool* has hardened steel serrated rollers on the end of a shank and is pressed against a revolving workpiece to raise a non-slip pattern on the surface. A *radius tool* has a cutting edge in the form of an arc of a circle, concave or convex, of uniform radius. A *form tool* has a cutting edge with a profile or contour to be reproduced on a workpiece. Some form tools are of the radial type but most of those for screw machines are tangential. A *skiving tool* is fed tangentially over or under a revolving workpiece for finish forming.

13.6 MULTIPLE-POINT TOOLS

Most drills, countersinks, counterbores, spotfacers, milling cutters, reamers, and taps for manufacturing are

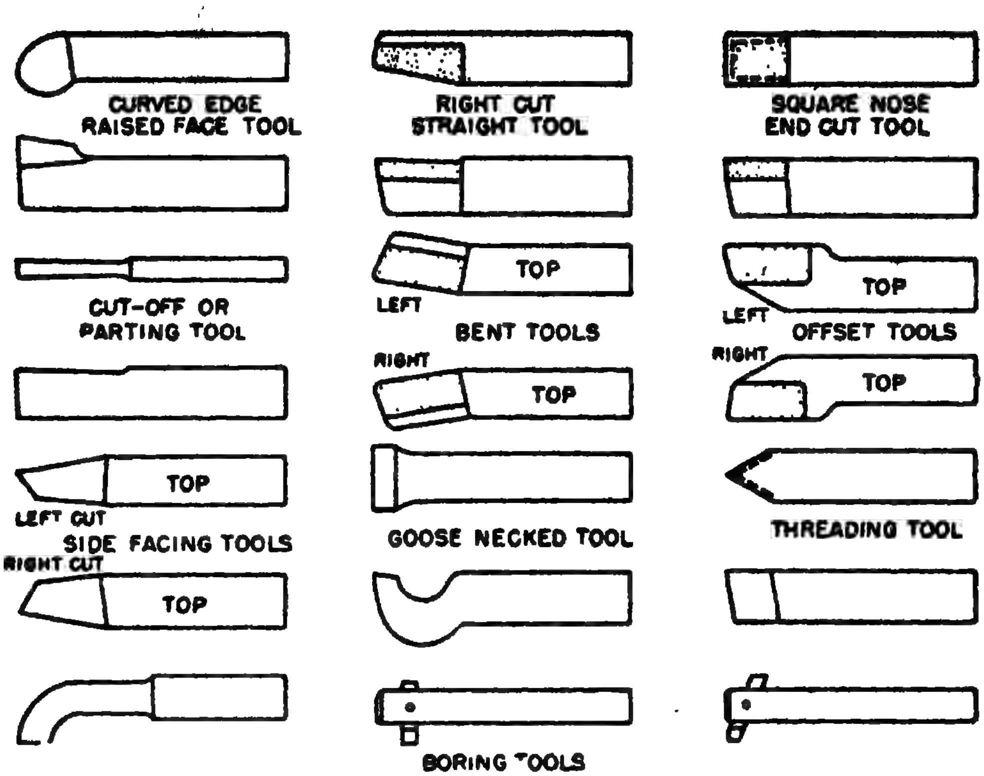


FIG. **10.20** SINGLE POINT CUTTING TOOL SHAPES.

standard commercial items. The tool engineer's main consideration is selecting them from manufacturers' catalogs in which they are described. Even where special tools of these kinds must be designed, the problem is usually one of modifying a standard tool to meet a specific situation. A multiple-point tool is basically an arrangement of single-point tools each of which has angles and other features corresponding to those described for single-point tools.

Specifications for standard multiple-point tools are given in the American Standards Association Bulletins *ASA B5.12-1950, Twist Drills; ASA B17f-1930, Woodruff Keys, Keyslots, and Cutters; ASA B5.18-1943, Spindle Noses and Arbors for Milling Machines; ASA B5c1-1947, Nomenclature for Milling Cutter Teeth; ASA B5.3-1950, Milling Cutters; ASA B5.14-1949, Reamers; ASA B5.4-1948, Taps;* and *ASA B5.11-1937, Adjustable Adapters.*

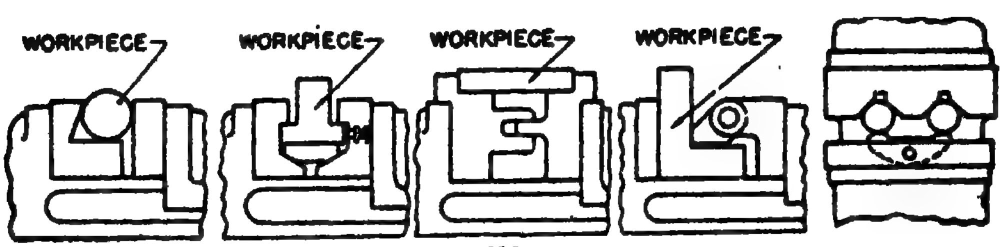
14. FIXTURES AND JIGS

A *fixture* is a device that holds one or more pieces while work is being done. A *jig* also guides a tool that does the work.

14.1 TYPES OF FIXTURES AND JIGS

Fixtures may be classified according to the kinds of operations on which they are used, such as milling,

FIG. **10.21** SPECIAL VISE JAWS.



Doyle, *Tool Engineering: Analysis and Procedure*, p. 398, Courtesy of the Swartz Tool Products Co.

FIG. **10.22** A UNIVERSAL JIG.

lathe, turret lathe, boring, tapping, welding and assembly fixtures. For any one kind of operation, fixtures of different construction may be used. Thus, the name of a fixture may be descriptive of its features, such as a vise, plain, faceplate, vee block, gear tooth, or indexing fixture. Examples of special jaws for standard vises to make vise fixtures are given in Fig. 10.21.

Jigs may be designated by operation, such as drilling, reaming, or boring, but mostly are limited to few kinds of operation and are called by names descriptive of their purposes, shapes, or features of construction, such as plate, ring type, template, channel, box, leaf, diameter, vertical stand, angle, tumble, or built-up jig.

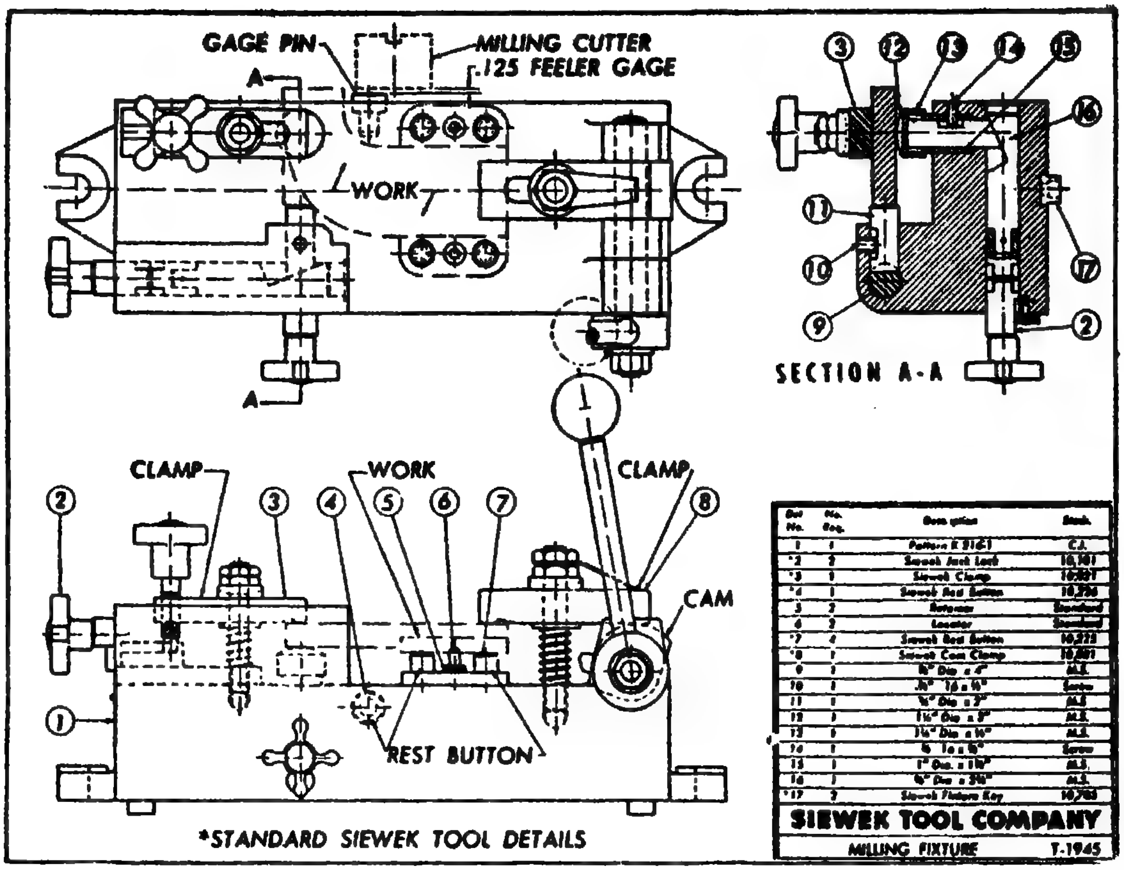
Universal fixtures and *jigs* are made by adding details to commercial bodies, as exemplified in Fig. 10.22, to adapt them to specific jobs. The body consists of a base over which a plate or tray is raised and lowered on posts to clamp or release the work. Jig guide bushings are pressed into holes jig-bored in the tray. A handle on the side actuates the device through a mechanism which commonly is self-locking. Universal fixtures and jigs are rigid, sturdy, accurate, easily converted from job to job, quick and easy to operate, open and accessible, and economical for medium- and large-quantity production.

14.2 DETAILS OF FIXTURES AND JIGS

A fixture or jig usually locates the workpiece it holds and has locating as well as clamping details. In addition to the locators, a piece may be supported by adjustable jack supports where needed. Revolving tools are guided by jig or guide bushings.

Fixtures for machining operations, especially milling, commonly have one or more reference surfaces to which cutters are set with feeler gages, as indicated in Fig. 10.23. These surfaces may be on details used for other purposes, but *set blocks*, *gage buttons*, or *gage pins* often are put on fixtures for the sole purpose of cutter setting.

Fixtures and jigs to be used on machine tools usually have details for positioning and fastening them on the machines. Milling and similar fixtures may have bolt slots for fastening and



Doyle, *Tool Engineering: Analysis and Procedure*, p. 156. Courtesy of the Siewek Tool Co.

FIG. **10.23** A LAYOUT DRAWING OF A MILLING FIXTURE WITH STANDARD DETAILS.

keys for aligning, as shown in Fig. 10.23. Many jigs are moved about on machine tables and have four legs or pads for each position in which the jig is to be set. A jig may have legs that can be swung into different positions or the jig may be placed on angle plates for drilling holes at angles.

The details of a fixture or jig are held together by being fastened to a *base, body,* or *frame.*

In addition to the basic details, others may be added to fixtures and jigs to provide various refinements. In some cases, ejection pins with an operating mechanism may be supplied to make removal of work easy. *Foolproofing details* make it impossible to load a workpiece except in its correct position. That is commonly done by placing blocks or pins so that the workpiece will clear them only if it is positioned correctly.

14.3 LOCATING DEVICES

Common types of locators are illustrated in Fig. 10.24.

Sight location by means of scribed lines, points, or sight holes is slow but applicable for rough workpieces varying considerably in size and produced in small quantities.

A *round pin,* with a bullet nose to facilitate loading, is used to locate a single machined hole. Such a pin may or may not have a flange, as in Fig. 10.24, but a dirt groove or chip clearance should always be provided at the bottom of the workpiece. A pin over about one inch diameter is cut away at three equally spaced spots around its circumference to prevent binding.

When two pins, or circular locators, are used together, the second should be a *diamond pin* to allow for the tolerances,

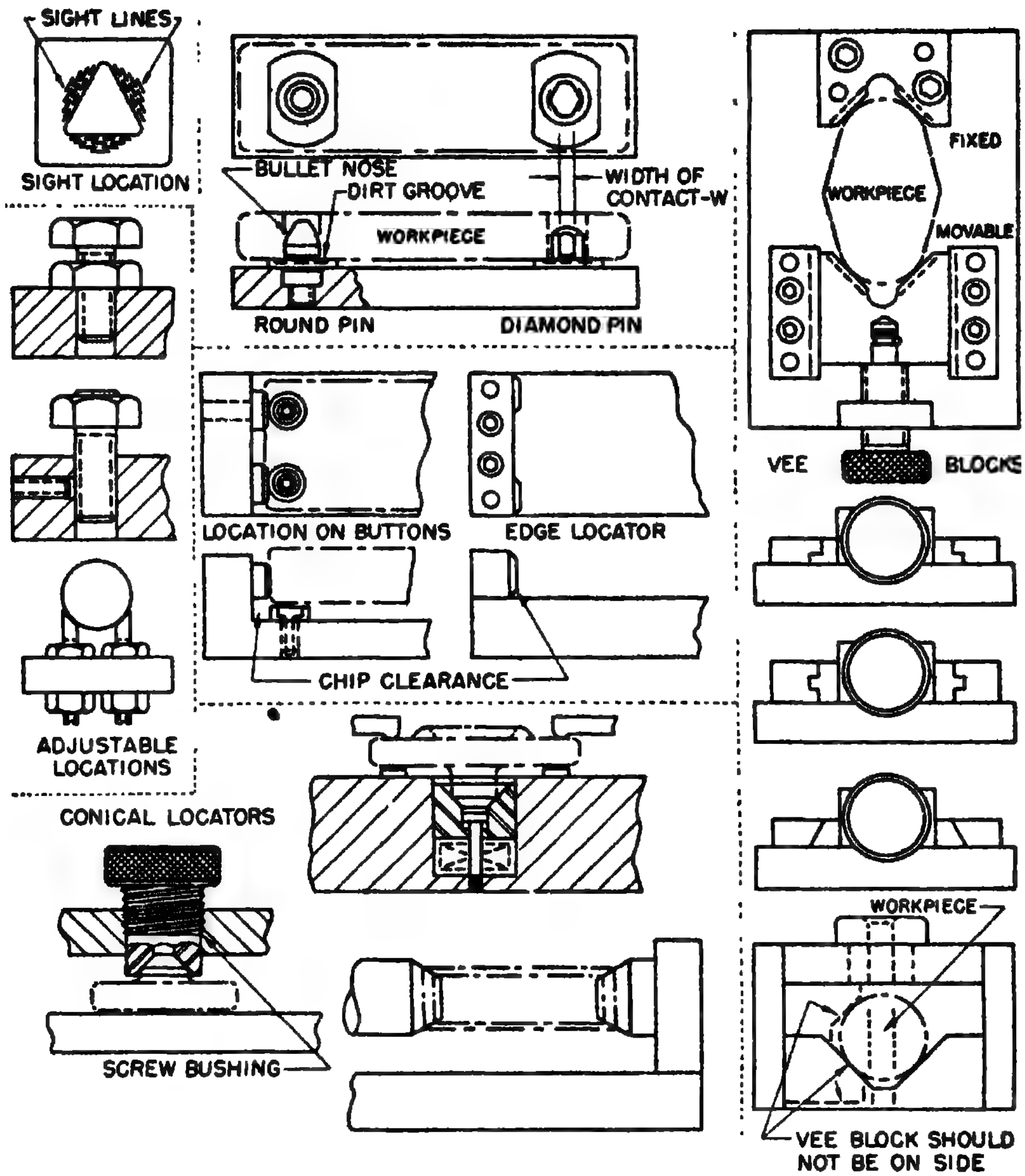


FIG. **10.24** LOCATING DEVICES.

S_1, on the dimension between hole centers, and S_2, between pin centers. The diamond pin confines the work in a direction at right angles to the center-line between the two pins. A width of contact, W in., as small as $\frac{1}{8}$ the nominal diameter of the diamond pin, but not less than $\frac{1}{32}$ in., is considered satisfactory. Also,

$$W = \frac{D}{S}(D - d) - \frac{S}{2}$$

where $S = S_1 + S_2$, D is the minimum diameter of the hole in the workpiece, and d is the maximum diameter to which the diamond pin can be made.

Hardened *rest buttons* have good wearing qualities with relatively small exposed surfaces. Thrust is better taken endwise than sideways by a button or pin. Large locating blocks should be relieved. Ample space should be provided for burr or chip clearance. Locators should be made easy to clean, by being as small as is consistent with durability; they should be accessible; they should be higher than surrounding areas, so that chips can fall off rather than on them; and they should be provided with

sharp *edges* where suitable to scrape loose particles from the work.

Vee blocks are widely used for locating round pieces. A 90° vee angle is best for most applications, but care must be taken that the axis is placed so that variations in workpiece location cause the least errors. Opposed vee blocks in pairs, with one fixed and the other movable but guided, have the effect of locating three points on a workpiece.

Internal and *external conical locators* at the ends of diameters allow for wide variations in workpiece length or diameters. The centers on a lathe are examples. The forging in Fig. 10.22 is centered between the equivalent of two external conical locators, one fixed and the other movable.

Adjustable locators often are needed for castings, forgings, or welded assemblies that vary appreciably in size, especially from lot to lot.

14.4 CENTRALIZERS

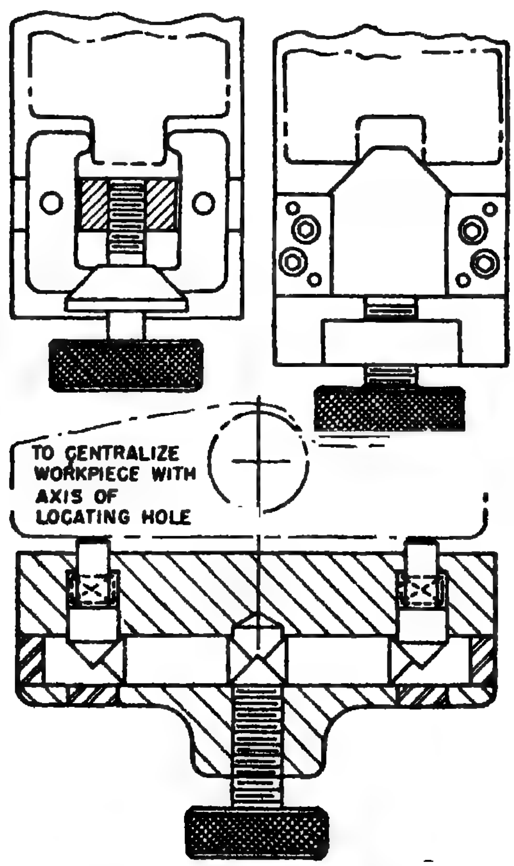
A centralizer is a device that locates the center line of two or more surfaces or points, as exemplified in Fig. 10.25. Conical locators and adjustable vee blocks act as centralizers. A centralizer may perform a clamping as well as a locating function.

14.5 CLAMPING DEVICES

The conditions that clamping devices must satisfy are described in Art. 8.2.

Two examples of *strap clamps* are seen on the fixture of Fig. 10.23. One is operated by a hand knob and screw and the other by a cam and lever. Both are held down by a stud, nuts, and spherical washer between the ends. A strap clamp may be arranged with the force applied

FIG. **10.25** CENTRALIZERS.



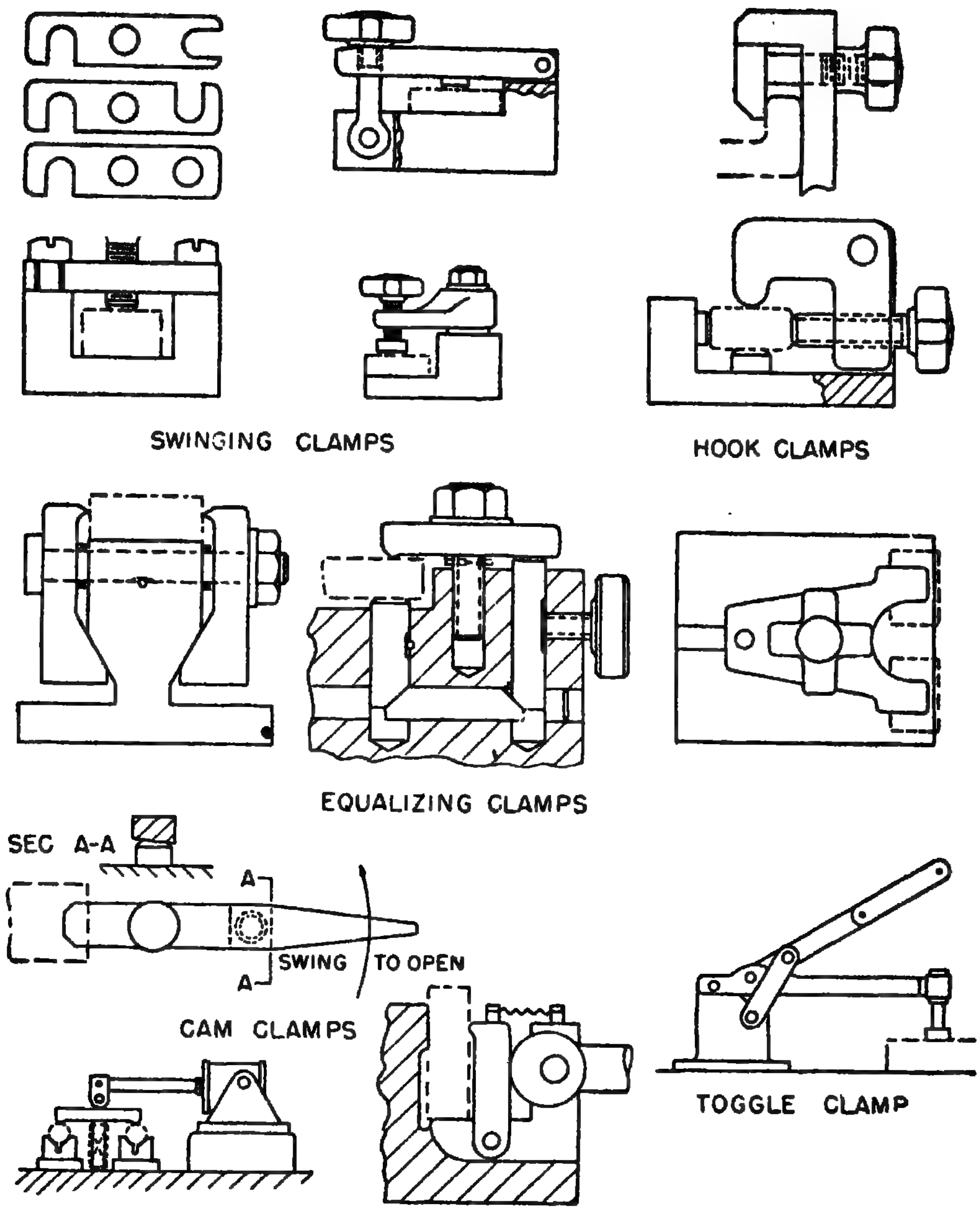


FIG. **10.26** COMMON CLAMPS.

to it from above at the stud and may have its back end bearing on a block or on another workpiece. Other typical clamping devices are shown in Fig. 10.26.

Most clamps employ some variation of the wedge, screw, cam, or toggle, with one or more levers, and are made irreversible. Screw-type clamps are simple, cheap, and versatile and can be made to act over a large range, but are relatively slow. Cam and toggle clamps are faster but more expensive and have limited ranges. Thus, they may not be suitable for clamping rough workpieces that vary considerably in size.

In general, the higher the rate of production, the more it is worth while to spend in making a clamping device quick and easy to operate. Air- or hydraulic-actuated clamping devices are much more expensive but take less time and effort for operation than manual ones. A study has shown that air-operated chucks require on the average ¼ of the time for operation that manual chucks do.

Even with simple devices, much can be done to promote clamping efficiency. Each strap clamp of Fig. 10.23 is supported by a spring around the stud to keep the strap from falling down when withdrawn from the work. Such springs are partly enclosed on some clamps to keep chips from clogging them. The straps are slotted so they can be slid away from the work. A pin projecting from the cam withdraws and returns the right-hand strap when the cam is loosened and tightened. The tightening screw of the left-hand clamp is guided in a groove to control the strap when it is moved back. Stops are helpful to control swinging clamps.

14.6 MECHANICS OF CLAMPS

The force exerted in tightening a clamp manually depends upon the strength of the operator and the effort he is willing to make. From 50 to 100 in. lbs. may be exerted on a hand knob. Small, knurled screw heads are not consistent because even a little wetness or oiliness makes them rather slippery. The forces in Table 10.10 are those that studies have indicated are exerted on various types of levers. A clamp is designed to deliver the required clamping force when the input is low but to be able to withstand the highest force likely to be imposed on it.

The force exerted by an air or hydraulic cylinder is $F_c = 0.7854 (D^2 - d^2)P$. The diameter of the piston is D in., and of the rod d inches. Most factories have air pressure, P, of 80 to 100 pounds per square inch, but it may drop to as low as 40 to 50 pounds per square inch in remote areas. Commercial hydraulic units are available to supply almost any pressure up to 1,200 pounds per square inch. A clamp is less likely to stick in closed position if closed by pressure applied to the rod side of the piston. Danger of a clamp opening as a result of pressure failure is eliminated by transmitting the clamping force through a locking mechanism, such as a cam.

A screw or nut exerting a minimum force of W pounds and a maximum force three times as large and capable of a working stress of 10,000 pounds per square inch should have a nominal diameter in inches of $d = 0.0235\sqrt{W}$. The torque in in. lbs. that must be exerted on an N.C. thread screw or nut is approximately $T = 0.2dW$.

A desirable width, in inches, for a strap clamp is $w = 2.3d + 1/16$, only slightly more than the diameter of the proper washer for the stud of diameter d in. With the nut and washer bearing halfway between the ends of the strap of length L in., a reasonable thickness for the strap is $h = 0.46\sqrt{dL}$.

An eccentric circular cam is cheaper to make but must be larger to stay locked and gives less mechanical ad-

TABLE 10.10 MANUAL FORCES EXERTED ON VARIOUS TYPES OF LEVERS

	Force in lbs.		
Type of lever	*Low*	*Average*	*High*
Single lever:			
Push or pull vertically from about 20 to 35 in. above floor level.	50	95	140
From about 35 to 50 in. above floor level.	30	65	100
Push or pull horizontally.	30	65	100
Cross bars:			
Push or pull vertically or horizontally from convenient position.	80	160	240
Handwheel:			
Vertical and parallel to body.	60	125	190
Vertical and perpendicular to body.	80	160	240
Horizontal.	70	140	210

vantage than a spiral cam under the same conditions. The locking action in either case depends upon friction at the cam face and may be impaired by lubrication or vibration. The minimum locking radius in inches of a spiral cam is $R = l/2\pi f$, where l is the lead in inches, and f is the coefficient of friction at the cam face. If $f = 0.1$, $R = 1.6l$. The minimum radius in inches for a circular cam of eccentricity e in. or throw T in. is

$$R = e\left(\cos\theta + \frac{\sin\theta}{f}\right) = \frac{T}{1-\cos\theta}\left(\cos\theta + \frac{\sin\theta}{f}\right).$$

The angle of throw is θ.

The torque in in. lbs. to cause a spiral cam to exert a clamping force of F lbs. is approximately

$$T = F\left(\frac{l}{2\pi} + Rf + rf\right)$$

where r is the radius of the pivot in inches. For a circular cam, it is approximately

$$T = F(e + Rf + rf).$$

Some manufacturers of clamping devices specify the forces that tests have shown their products are able to deliver.

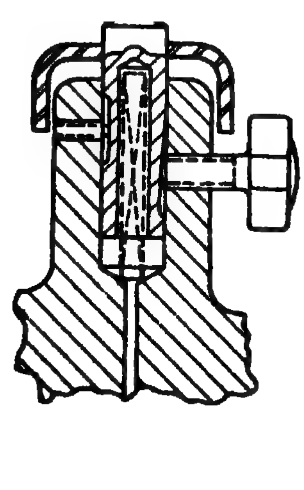
14.7 ADJUSTABLE JACK SUPPORTS

A screw makes the simplest jack support, but with it the operator can distort the work if he is not careful. One form of jack screw has a ratchet head that limits the force that can be applied. Other types of jack supports are shown in Figs. 10.23 and 10.27. Operating time is saved when several jack supports are arranged to be locked or operated from one control.

14.8 JIG BUSHINGS

Typical jig bushings are depicted in Fig. 10.28. *Headless bushings* are pressed into place, may be used alone for low production, and serve as liner bushings. A head keeps a bushing from being pushed through the plate, provides a place for clamping, helps protect the soft bushing plate from misdirected cutting tools, can serve as a bearing for a depth stop collar on a tool, and is the place where a slip bushing is grasped. *Fixed* or *plain head type bushings* are pressed in place to remain until worn out or no longer needed. If expected to be replaced when worn, a bushing is inserted in a liner with or without a head. A clamp or lock screw keeps a bushing from being pushed out by chips or from turning with the tool and wearing the hole in which it fits. A *slip renewable bushing* can be turned back slightly and withdrawn from the hole. Slip bushings can be used to guide tools of different sizes, such as a drill and reamer, in succession in one hole, or one bushing may be used for several holes in a workpiece where production

FIG. 10.27 ADJUSTABLE JACK SUPPORT.



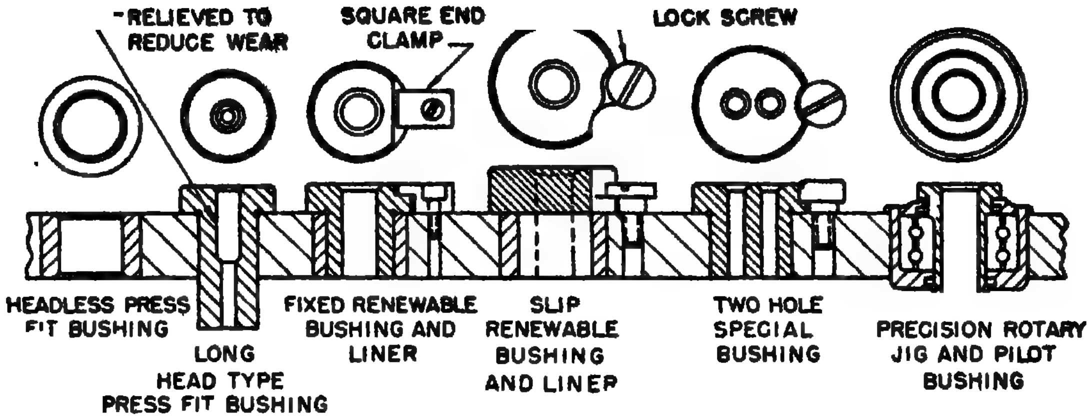


FIG. **10.28** JIG BUSHINGS.

is low. *Screw bushings,* like the one in Fig. 10.24, act as locators or clamps as well as tool guides.

Jig bushings may be purchased in standard sizes listed in manufacturers' catalogs and in *ASA B5.6-1941, Jig Bushings,* based upon jig-plate thicknesses of $\frac{5}{16}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{3}{8}$, and $1\frac{3}{4}$ inches. They are available ground to size or $\frac{1}{64}$ in. oversize for fitting. Special bushings are made to suit unusual conditions, such as when extra length is required or two holes are too close together for separate bushings.

A tool is guided best when a bushing is close to the work surface, but chips must pass out through the bushing and cause wear. That arrangement gets the chips out of the jig, which is particularly helpful where long and thin chips may become tangled in the jig. Wear is reduced by keeping the bushing away from the work surface a distance equal to about $1\frac{1}{2}$ times the tool diameter. Thus, both positions have merits, and the one to adopt depends upon conditions in each case. However, compromise is not desirable because it has the disadvantages of both extremes.

15. PUNCHES AND DIES

15.1 APPLICATIONS

Punches and dies are used in many industries for metal cutting, forming, stretching, and squeezing.

Metal-cutting operations include blanking, piercing, perforating, shearing, parting, cutting off, trimming, slitting, notching, shaving, and broaching. In *blanking,* the piece wanted is punched from the stock. Holes are punched in a part by *piercing,* small closely spaced holes by *perforating.* Parts are separated from each other or from the parent stock and cut to length by *shearing, parting,* and *cutting off. Trimming* is the shearing of the flanges of drawn shells or forgings. *Shaving* removes 0.001 in. or so from the edge of a blank to make it accurate and square and to give it a good finish.

Metal forming beyond the elastic limit by bending or shaping, curling, wiring, stamping, embossing, and beading operations is not severe. *Bending* stresses a part in tension on one side and in compression on the other side of its neutral axis to form one or more angles. *Curling, wiring,* or *false wiring* consists of bending over the edge of a cup or bucket with a curl to form a smooth rim. The wire inside of the curl is usually omitted in modern practice. The thickness of the material is not changed appreciably in *stamping, embossing,* or *beading* to raise or depress a pattern or rib on thin metal. Embossing is somewhat more severe and produces a sharper impression than stamping.

Drawing, redrawing, reducing, bulging, and ironing are stretching operations for producing relatively deep cavities by working or forming materials severely. In *drawing,* the metal is made to flow from a flat blank into a cup or shell with

a continuous wall. Several draws may be necessary to produce a part, and operations after the first are called *redrawing* or *reducing*. *Bulging* is commonly performed to bulge out the contour of a cup between the rim and bottom. *Ironing* thins the walls by redrawing and at the same time squeezing a cup between the punch and die opening.

Squeezing operations are coining, sizing, swaging, forging, upsetting, and extruding. *Coining* is a severe high-pressure operation in a closed die causing the material to flow into sharp designs on the surfaces of a piece. In *sizing*, a part is squeezed to a definite thickness. Tolerances of 0.005 in. or less are commonly held in sizing parts in production. *Swaging*, *forging*, and *upsetting* are operations for squeezing slugs into definite shapes in production. *Forging* is done hot or cold and is called *upsetting* when done lengthwise on the end of a piece. *Extruding* is the method of compressing metal and causing it to flow rapidly through an orifice with a definite cross section that is imparted to the product.

15.2 TYPES OF DIES

A *punch* is a detail of a press tool that enters the opening in another detail called the *die* or *die block*. The complete assembly or press tool is also called a *die*. A die that performs a single operation is named for that operation, such as a blanking die, bending die, or coining die.

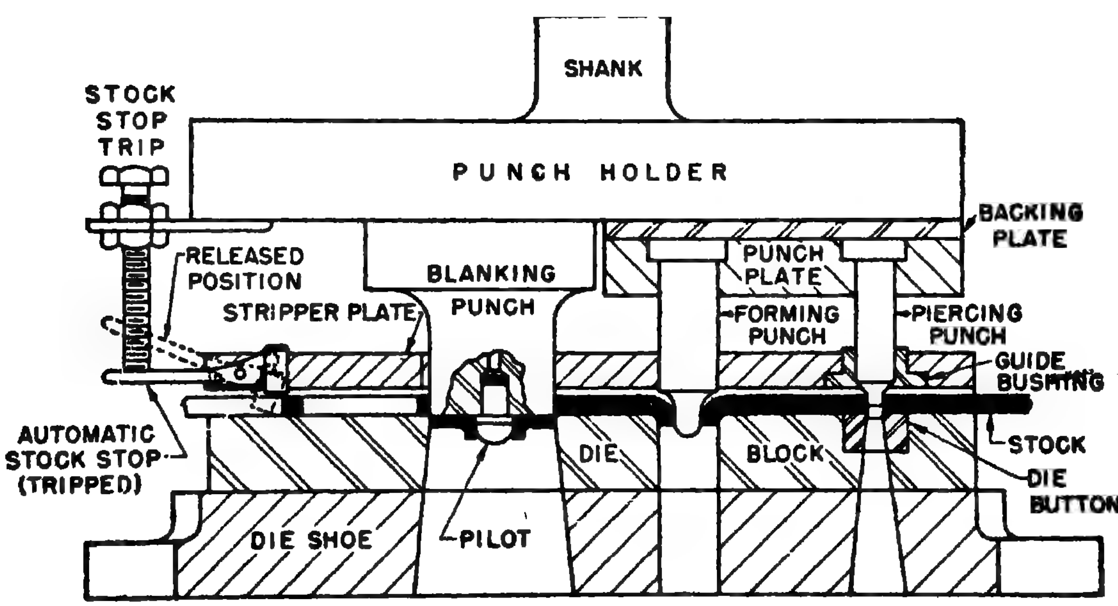
A *progressive* or *follow die* has a series of stations. Each piece in a strip passes from station to station and through a series of operations, such as piercing, forming, and blanking, as in Fig. 10.29. At each stroke, a piece or pieces at the end of the strip are finished, and the strip is moved forward.

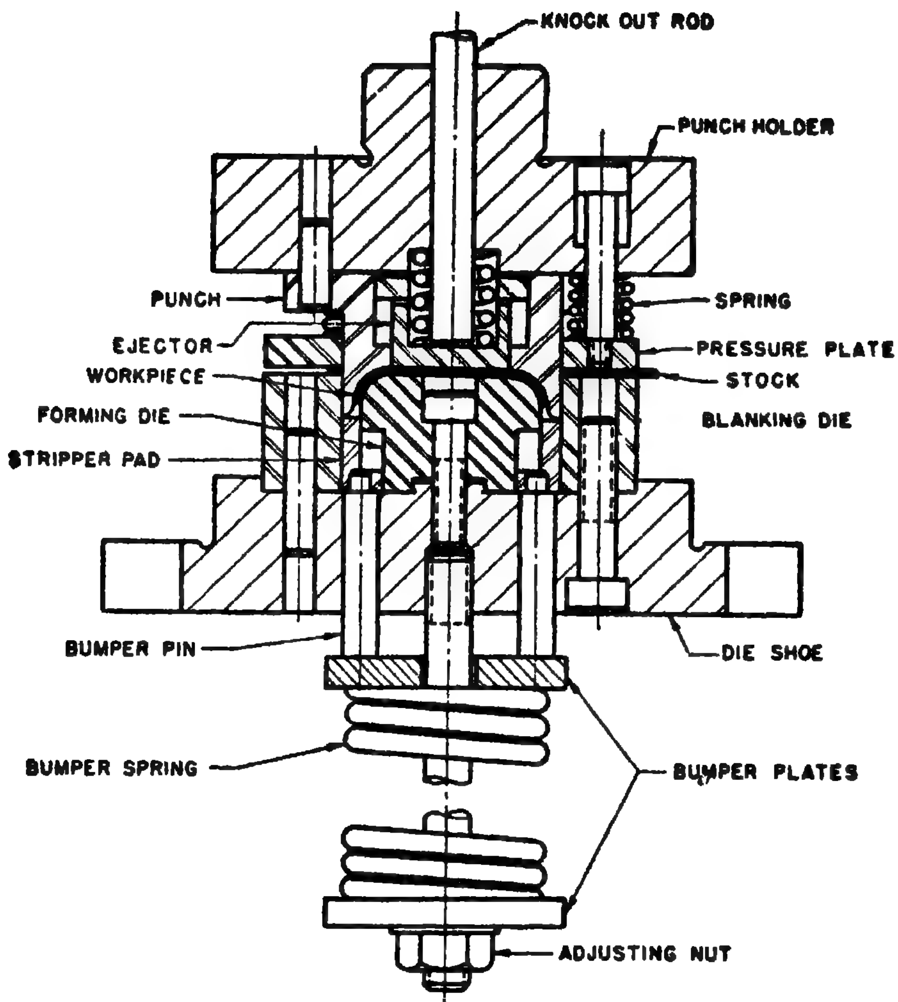
A *compound die* has a single station in which blanking and piercing or perforating are done on one piece at each stroke. The blanking punch contains the piercing die openings and is usually on the bottom, with the blanking die and piercing punches on top.

A *combination die* performs cutting and forming or drawing operations simultaneously in one station, as exemplified in Fig. 10.30. Because all operations are performed while a piece is in one station, combination and compound dies produce more accurate parts than progressive dies, but as a rule are more expensive to make and maintain.

A *sectional die* is composed of assembled sections instead of having a solid die block. *Cam die* is the name applied to a type of die often used for

FIG. 10.29 A PIERCING, FORMING, AND BLANKING PROGRESSIVE DIE.





Doyle, *Tool Engineering: Analysis and Procedure*, p. 419.

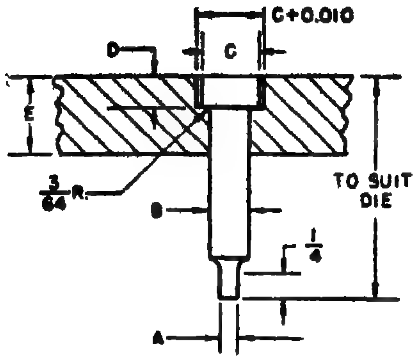
FIG. **10.30** A COMBINATION BLANKING AND DRAWING DIE.

forming and side-piercing operations; it has horizontal or angular slides carrying punches actuated by cams on the descending punch holder.

Several types of dies have cost-saving features for low production. A *hinge-type die* has its upper member or punch holder hinged to the die shoe for compactness and ease of setup. A *continental die* has a loose punch set on top of the material and pushed through the die block for each piece. A *magnetic die* has its punch and die block held by a magnetic die set for temporary operation. An *adjustable perforating die* is made up of standard commercial punching units bolted to the members of a die set. Assorted jobs can be tooled easily by changing the positions of the punching units.

15.3 DIE SETS

A production die is conventionally constructed upon a *die set* that consists of a punch holder and die shoe kept in permanent alignment by two or more vertical leader or guide pins. The guide pins are fastened to the die shoe, and the punch holder, often bushed, slides over them. The die shoe is bolted to the bolster plate of the press. The punch holder is bolted to or has its shank clamped in the press ram. The punch holder and die shoe are cast iron



Dimension, in.		For Stock up to 3/32 in.			For Stock over 3/32 in.		
A	*B*	*C*	*D*	*E*	*C*	*D*	*E*
0.031 to 0.250	0.2505	0.375			0.437		
0.251 to 0.375	0.3755	0.500			0.562		
0.376 to 0 500	0 5005	0.625	5/32	11/16 min.	0.750	1/4	15/16 min.
0.500 to 0.750	0.7505	0.750			1.000		
0.750 to 1.000	1.0005	1.125			1.250		

FIG. **10.31** PIERCING PUNCH AND PUNCH PLATE DIMENSIONS.

or semi-steel for ordinary purposes and steel for highest quality. The punches and die block are positioned in a die set so that the resultant of all vertical forces acting during a stroke passes through the center of the ram. Die sets are available commercially in a large variety of styles and sizes.

15.4 PUNCHES, PLATES, AND PADS

A large blanking or forming punch usually is made with a flange by which it is bolted and doweled to the punch holder after being aligned with the die block in assembly.

The length of the shank of a blanking punch for quantity production should include ⅛ to ¼ in. for grinding to resharpen it during its life and enough more to reach the die block through the stripper plate and to shear the stock after the punch has been ground down. For stability, the width of the flange should not be less than the height of the punch. The nose of a drawing punch should have a smooth radius all around of four to six times the stock thickness.

Piercing punches are pressed in a punch plate, as shown in Fig. 10 29, and the plate is bolted and doweled to the punch holder. Head-type punches are widely used but require that the plate be removed to remove broken punches, which may have to be done frequently with small punches. Commercial punches are available with locking devices that make punch replacement quick and easy. A punch that is not round must be kept from turning by a pin through its flange and the punch plate. Small punches are often made shorter than large punches by the depth of penetration to shear the stock to avoid crowding and breakage. Proportions of piercing punches and plates are suggested in Fig. 10.31. It is generally difficult to pierce a hole smaller in diameter than the thickness of the stock.

A hardened *backing plate* or *punch pad* may be inserted behind small punches, as shown in Fig. 10.29, to keep them from digging into the soft punch holder and working loose.

15.5 DIE BLOCKS

Average die-block thicknesses are indicated in Fig. 10.32. The distance between any cutting edge and an outside edge of a die block should not be less than the thickness of the die block to avoid cracking in heat treatment and service. A die opening for blanking or piercing is straight for a short distance below the top of the block and then is tapered ¼° to ¾° on a side on through the die block and shoe to prevent blanks and slugs from sticking. Satisfactory practice is to make the straight portion ⅛ in. long for stock less than ⅛ in. thick, and equal to the stock thickness when it is more than ⅛ in. thick.

The edge of a die opening over which metal is drawn is given a radius four to

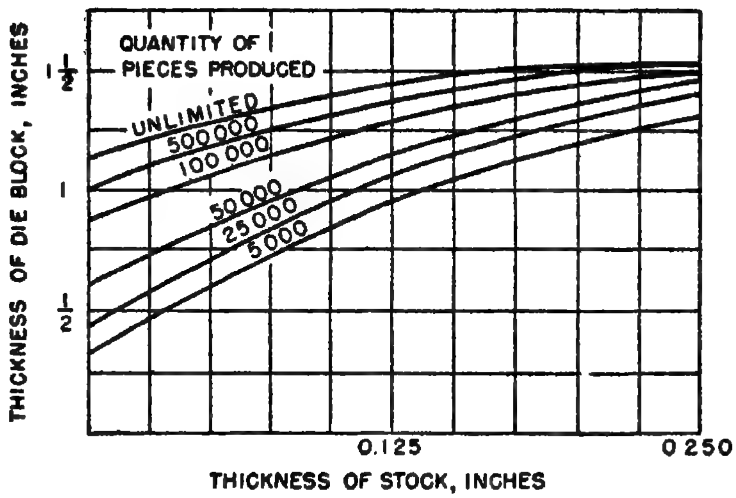


FIG. **10.32** AVERAGE DIE BLOCK THICKNESSES.

six times the metal thickness and is highly polished.

Most punches and die blocks are made of tool and die steel. A large variety of steels is available to suit many purposes. Nonferrous alloy and cemented carbide die-block inserts, punch tips, and solid small punches have proved successful for severe service and high production. Cemented carbide dies are reported to last 20 to 40 times longer than steel dies for cutting, and 10 to 30 times longer for forming. For low production, especially with soft work materials, dies are made of rubber, plastic materials such as Masonite, and of low-temperature metals and alloys that are quicker and easier to fabricate and sometimes more available than steel.

Die buttons, like that in Fig. 10.29, are commonly inserted for piercing holes in long-run die blocks because they can be replaced if breakage or wear occurs. The bushing should extend about three-quarters of the way through the block to allow for grinding and still leave ample bearing in the block.

15.6 DIE CLEARANCES

A definite space or clearance is provided all around between a punch and die, as illustrated in Fig. 10.33, to obtain a clean cut and a minimum cutting force. A hole punched in a piece is the size of the punch. The slug or blank punched out is the size of the die opening. Thus, for piercing, the punch is made to the hole size desired, and the die opening is made larger than the punch by the amount of the clearance on two sides. For blanking, the die opening is made to the size of blank required and the punch is made smaller.

The clearance between a drawing punch and die usually is more than the thickness of the stock, as much as 50 per cent more for the first draw and 25 per cent for subsequent draws when thickening of the material is not objectionable. Ironing clearance is less than the original thickness of the stock, with a theoretical maximum reduction of 50 per cent in wall thickness, although as much as 64 per cent has been reported.

15.7 STRIPPER PLATES

The two kinds of *stripper plates*, *fixed* and *spring*, serve to strip material from punches, hold down material for forming or drawing, and guide punches. A spring stripper that acts as a pressure plate is shown in Fig. 10.30. A spring stripper that guides piercing punches must be accurately held in line by guide posts. A stripper that does not guide the punches may have clearance of 0.010 to 0.015 in. around small punches, and 0.001 to 0.005 in. around sturdy punches.

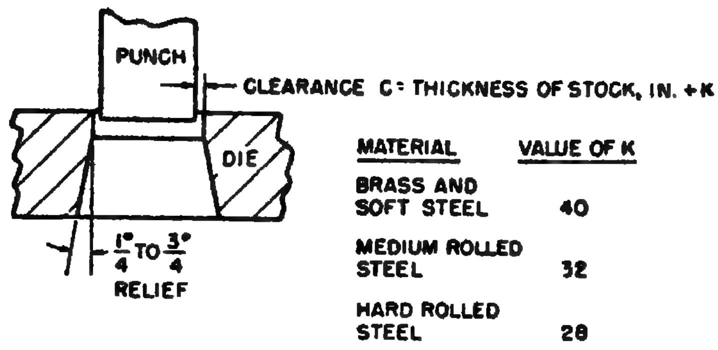


FIG. **10.33** DIE CLEARANCE.

A fixed stripper plate, as on a progressive die, has a lengthwise slot to guide the stocks. Proportions found adequate for stripper plate slots by a large manufacturer are given in Table 10.11. A safe thickness in inches for a stripper plate above the slot is $T = W/30 + 2t$, where W is the stock width in inches, and t is the stock thickness in inches. The screws that hold down the stripper plate and die block must have sufficient strength to resist the stripping force, which with dull tools may amount to 15 per cent of the cutting forces.

Stripper plates are made of machine steel for ordinary dies, tool steel unhardened for good-quality dies, and hardened for severe service. Guide bushings, like that in Fig. 10.29, similar to jig bushings, are inserted in soft stripper plates to inhibit wear in guiding punches.

A knockout supplementing the springs actuating the ejector in Fig. 10.30 is depressed by a positive stop on the press.

15.8 STOPS AND PILOTS

Finger or *starting stops,* as in Fig. 10.34, position the stock in one station after another when a new strip is started through a die, and retract when not needed. *Stock aligning pins* are spring-loaded to press the stock against one side of the stripper-plate slot. After a strip has been started through a die, it is located for one piece after another by a *stock stop* that usually registers against the scrap left between the blank openings. A simple stop is a fixed pin. A *swinging stop* is shown in Fig. 10.34. The strip is moved under the stop, which swings out of the way, and then is brought back to bear against the stop. This stop is slower than an *automatic stop,* one version of which is shown in Fig. 10.29. The pin that locates the stock is a loose fit in a hole in the stripper plate. A trip on the punch holder pushes the handle of the stop down when the ram descends. This raises the stop pin which is pressed by a spring against the right side of the hole and falls on top of the stock when the ram ascends. When the stock is moved forward, the pin falls into the next blank opening. The side of the opening that comes up next pushes the pin against the right side of the hole in the stripper plate, and the stock is stopped and positioned.

To produce accurate parts, a progressive die has pilots that register in holes pierced in the first stations to align them with the blank. If a part does not have

TABLE **10.11** DIMENSIONS OF SLOTS IN FIXED STRIPPER PLATES

Width of stripper slot		*Depth of stripper slot*	
Thickness of stock, in.	*Slot wider than stock by ___ in.*	*Thickness of stock, in.* (T_1)	*Depth of slot, in.*
0 to 0.040	5/64	0 to 0.0625	0.025 + 2T
0.041 to 0.080	3/32	Over 0.0625	0.090 + T
0.081 to 0.120	7/64	(For silicon steel the minimum	
Over 0.120	1/8	depth is 1/8 in.)	

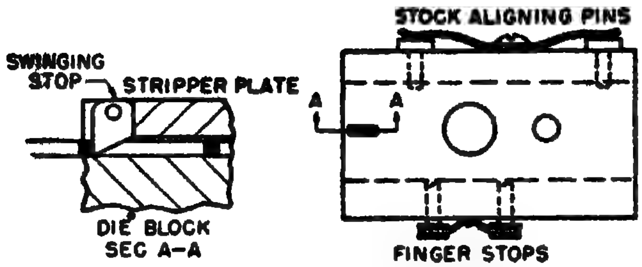


FIG. **10.34** STOCK STOPS.

holes in itself suitable for piloting, holes for that purpose may be pierced in the scrap. A simple form of pilot is shown in Fig. 10.29. Other types and proportions are given in Fig. 10.35. If misfeed occurs, a spring-loaded pilot retracts without causing damage. A die should be arranged so that when the pilots register they draw the stock a few thousandths of an inch away from the stops and side of the stripper plate.

Parts fed individually into a die are commonly located in a *nest* that should be three to four times as high as the blank thickness and should have well-rounded edges on top.

A *shedder, spring,* or *kick pin,* as shown in Fig. 10.35, dislodges blanks or slugs that tend to adhere to the face of a punch.

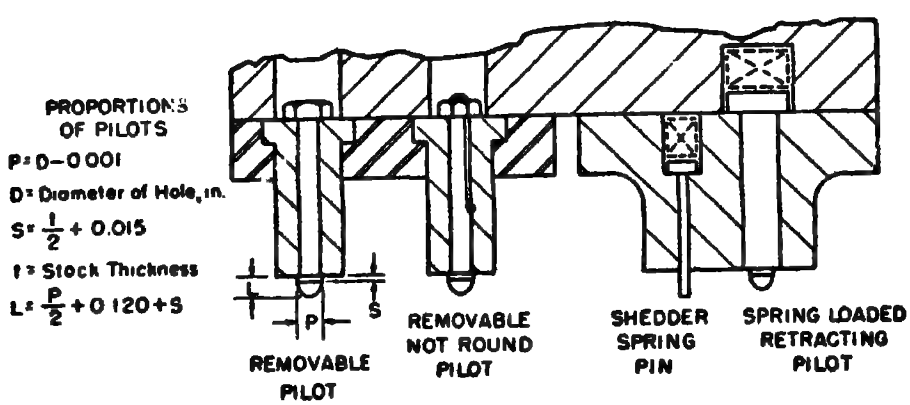
Stop blocks about 1½ inches in diameter may be placed in a die set within the slide area of the press to help set up by indicating when the die is closed and to prevent the die from closing in storage.

A punch that cuts, shaves, or forms mostly or entirely on one side must be backed up to prevent excessive deflection. A backing-up surface may be provided on the die block in some cases. Otherwise, the punches are reinforced by bearing against backing blocks that often have wear plates of hardened and ground tool steel or bronze, with provision for lubrication and adjustments to compensate for wear. The heel of the punch must make contact with the backing-up surface before the punch acts.

15.9 PRESS DIMENSIONS

An important dimension of a press that must be considered in the design of a die is the *shut height,* which is the distance from the top of the bolster plate to the bottom of the ram when the ram is at the bottom of its stroke and its adjustment is all the way up, resulting in the maximum vertical space the die can occupy when closed. Other dimensions to be considered are the length of stroke, ram adjustment, diameter of hole in ram for punch-holder shank, bolt holes for clamping punch holder to ram, distance from center line

FIG. **10.35** PILOTS.



of shank opening to press frame, relation of axis of shank opening to bolster plate, distance between ways if ram goes up between ways, sizes of openings in bolster plate and press bed, and sizes and positions of bolster plate holes for bolts. If a roll feed device is to be used on the press, the direction of feed and the distance from the top of the bolster plate to the center of the roll feed must be ascertained.

15.10 STOCK LAYOUT

Planning the size of stock and arrangement of the pieces for least scrap loss and most economy is one of the most important steps in the design of a die. This leads to the arrangement of the punches in the die. Templates of the blank may be cut out and tried in all possible arrangements to find the one requiring the smallest total amount of material per piece. The parts should be arranged to utilize standard commercial widths of stock if possible. A part to be bent later must be blanked in proper relation to the grain of the material. Bending is done best at right angles to the grain.

The side of a blank next to the punch face has square edges and is called the flat side. It must be on one specific side of the blank in many cases. The other side has slightly rounded edges and is called the round side.

15.11 DRAWING

Because drawing is a severe operation, it must often be done in stages, and a series of tools must be provided accordingly. As a rule, a part requires more than one draw if the ratio of its height to diameter exceeds ¼ to ¾; more than two draws if the ratio exceeds ⅝ to 1⅛; more than three draws if the ratio exceeds 1⅛ to 2; and so forth, depending upon the material ductility and condition and the nature of the operation. A corner radius in a shell should exceed four times the stock thickness if extra operations are to be avoided. Considerations are more complex for drawing rectangular and irregular parts, such as auto body parts.*

The area of a single drawn cup of thin material and small corner radius is the same as the area of the blank, for practical purposes. If its metal thickness t and corner radius r are considerable, a cup of outside diameter d and inside height h may be drawn from a blank of the same material volume and diameter†

$$D = [(d - 2r - 2t)^2 + 4(d - t)(h - r) + 2\pi(r + 0.4t)(d - 0.7r - 0.3t)]^{\frac{1}{2}}$$

The actual volume ratio may vary slightly with the metal hardness and die construction.

Stock of about 13 gage or heavier may be drawn in a simple shape without pressure applied to the blank. Under other conditions, the blank must be confined between pads under pressure while being drawn. With a single-action press, the pressure may be supplied by springs, as in Fig. 10.30, rubber pads, or hydraulic or air cylinders. With a double-action press, the blank is held mechanically by the first action of the press while being drawn by the second action. The actual pressure required is difficult to specify for any particular case and is ascertained experimentally.

16. GAGES‡

16.1 TYPES OF GAGES

A *gage* is a device for determining whether one or more dimensions of a manufactured part are within specified limits. A *working gage* is used by an operator on a machine to check the work he is producing. *Inspection gages* are used to check finished pieces. *Reference* or *master gages* are reserved for checking other gages.

* E. V. Crane, *Plastic Working of Metals and Non-Metallic Materials in Presses* (New York: John Wiley & Sons, Inc., 1945).

† Crane, *Plastic Working of Metals and Non-Metallic Materials in Presses*.

‡ See Section 14, Inspection and Quality Control, Art. 9.

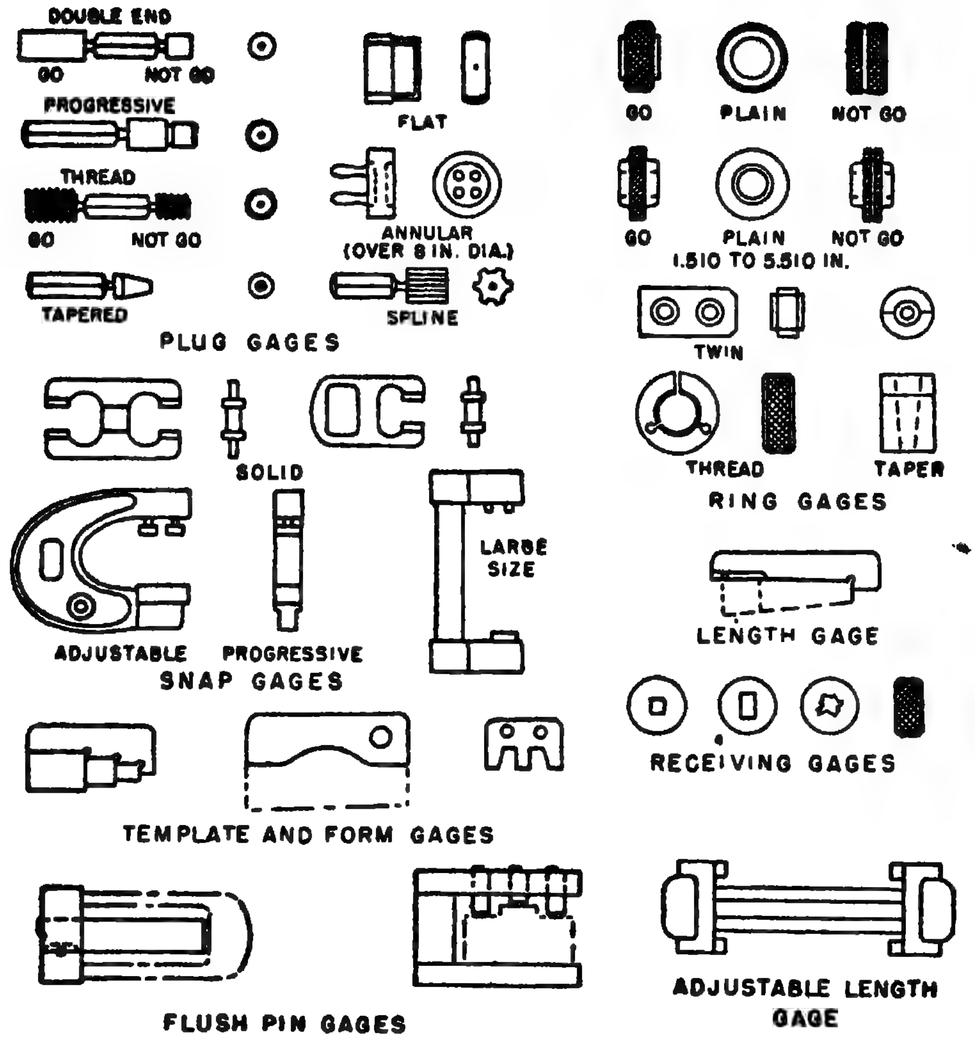


FIG. **10.36** TYPICAL GAGES.

A gage that checks the high and low limits of a dimension is called a *limit gage* or a "go" and "not go" gage. A *double-end gage* has a "go" member at one end and a "not go" member at the other end and must be applied twice to a workpiece. A *progressive gage* is quicker, with its "go" and "not go" members next to each other, but its action is sometimes limited. For instance, it is not suitable for probing the full depth of a blind hole. A *solid gage* is fixed for one set of limits. An *adjustable gage* can be set and locked to a predetermined size within its range.

Typical *fixed gages* are illustrated in Fig. 10.36. An *indicating gage* is a device that reflects one or more dimensions of a workpiece on a visual scale. A *combination gage* checks more than one dimension on a workpiece at one time.

16.2 GAGE STANDARDS

The dimensions of standard gages are specified in Commercial Standard CS8-41, *Gage Blanks*, U. S. Department of Commerce.

Tolerances for plain cylindrical plug and ring gages have been standardized as shown in Table 10.12. Class XX gages are precision lapped for the highest degree of accuracy practicable and should be used only for the final inspection of close-tolerance dimensions and as reference gages. Class X gages are also precision lapped and are usually applied to

TABLE 10.12 STANDARD GAGE TOLERANCES FOR PLAIN CYLINDRICAL PLUGS AND RINGS*

Nominal size of dimension in in. Above	To and including	Gagemakers' tolerance in in. Class of gage xx	x	y	z	zz (Ring gages only)
0.029	0.825	0.00002	0.00004	0.00007	0.00010	0.00020
0.825	1.510	0.00003	0.00006	0.00009	0.00012	0.00024
1.510	2.510	0.00004	0.00008	0.00012	0.00016	0.00032
2.510	4.510	0.00005	0.00010	0.00015	0.00020	0.00040
4.510	6.510	0.000065	0.00013	0.00019	0.00025	0.00050
6.510	9.010	0.00008	0.00016	0.00024	0.00032	0.00064
9.010	12.010	0.00010	0.00020	0.00030	0.00040	0.00080

* Handbook H-28, *Screw Thread Standards for Federal Services* (Washington, D. C.: U. S. Dept. of Commerce, 1944). *Standard Gages* (Poughkeepsie, New York: Standard Gage Co.).

close-tolerance inspection. Class X to ZZ tolerances are progressively larger and the gages are used to inspect dimensions with correspondingly larger tolerances. Class Z is the regular commercial class of ring gage furnished when specifications do not call for exceptional accuracy. Class ZZ gages are ground but not lapped, are the most inexpensive of ring gages, and are suitable only for gaging small quantities of pieces with liberal tolerances.

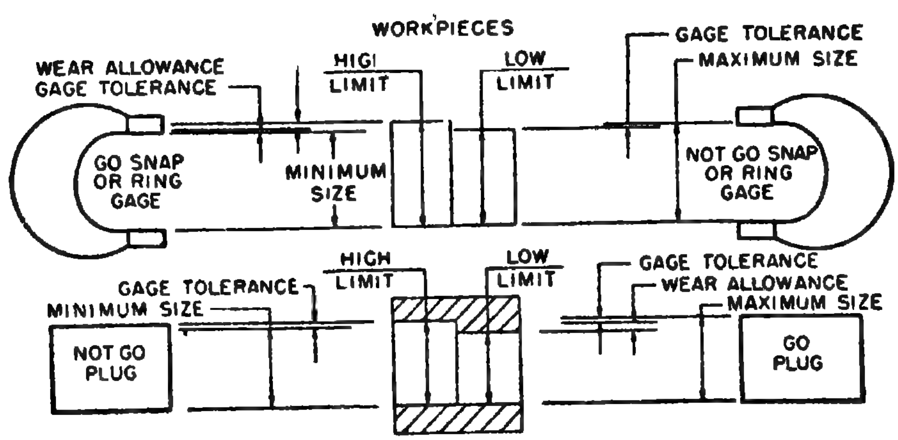
A gage tolerance is commonly limited to 10 per cent of the tolerance on the part dimension and often to 5 per cent for inspection gages. A closer tolerance than necessary should not be specified for a gage because the gage cost rises rapidly as the tolerance is reduced. If the tolerance of a part dimension is large, say 0.010 in., the gage makers' tolerance may be selected from the most liberal class and a substantial allowance may be made for gage wear.

16.3 GAGE POLICY

A number of systems and many variations of each are in use for assigning tolerances to gages. A policy developed by Ordnance engineers and especially well suited for liberal part tolerances is depicted in Fig. 10.37. This system provides for wear of "go" gages but not "not go" gages, always allows the gage maker a tolerance, prevents conflict between working and inspection gages, and always remains within the workpiece limits.

Three classes of thread gage tolerances and their applications are specified in Handbook H-28, *Screw Thread Standards for the Federal Services*.

FIG. 10.37 GAGE TOLERANCE POLICY OF ORDNANCE ENGINEERS.



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B 5.8-1936 *Chucks and Chuck Jaws.*
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Robert E. Donovan is Manager, Safety Division of the Personnel Department, Standard Oil Company of California. He has been with this company and involved in safety engineering work since shortly after he joined the company in 1922.

A native of Nevada, Mr. Donovan was educated in California and Nevada. He took the mining engineering course in the Mackay School of Mines at the University of Nevada. He served in World War I and then returned to Nevada to open a mining engineering office. He was soon employed by the U. S. Bureau of Mines as First Aid Miner and in that position offered the first first-aid classes ever to be given in the petroleum industry. He has been vitally concerned with safety and first aid in the petroleum industry ever since. He was employed by the Standard Oil Company of California as Safety Engineer in 1922 and was soon promoted to the position of Chief Safety Engineer, in which he organized the Safety Division for the entire parent company and all wholly-owned subsidiaries.

Mr. Donovan's work has been of considerable influence both in California and nationally. He organized the Department of Accident Prevention in the American Petroleum Institute in 1930 and has been Chairman of its Central Committee on Accident Prevention. He is a member of the Executive Committee of the American Society of Safety Engineers and is a past president of both that organization and the California Safety Society. From 1938 to 1953, inclusive, Mr. Donovan was Chairman of the General Safety Committee of the Western Oil and Gas Association and is still a member of that committee. He is a member of the National Safety Council, State Chamber of Commerce's Committee on Workmen's Compensation Legislation, Safety and Health Advisory Committee of the U. S. Department of Labor, and the Highway Safety Committee of the National Truck Owners Association.

Mr. Donovan has taught courses in Safety Engineering at the University of California and Stanford University.

SECTION **11**

Industrial Safety

Robert E. Donovan

1. INDUSTRIAL ACCIDENT EXPERIENCE AND COST

A tremendous bill is paid each year for the treatment and cure of disabilities to workmen resulting from on-the-job accidents. Most of this bill is paid by the industrial concerns, large and small, employing the men when the injuries were incurred. The National Safety Council reports that each year the visible costs to American industry for workmen's injuries are about $1,350,000,000. The indirect costs covering the money value of damaged equipment and materials, production delays, and time losses of other workers not involved in the accidents amount to about $1,300,000,000 per year. The visible costs include the medical and hospital expenses, death benefits, and workmen's disability compensation as provided for by the various federal and state workmen's compensation acts. These costs must come out of industry's profits, since the responsibility is placed by law on the employer. Whether the employer is a self-insurer or insures his risk with an

insurance carrier, he pays the cost of medical attention required by the injured employee and the compensation the employee receives during disability.

In addition to the cost that is paid by the employer, the injured worker also suffers financially, because his injury disability compensation never equals his earnings, except in some companies that have full-pay benefit plans. Even in such companies, there is a limit on the amount the injured worker can receive. Furthermore, many injuries leave the worker permanently disabled and may prevent him from earning at the same level as he did prior to the injury. If, despite his handicap, his employer keeps him at the same wages as before the injury, the employer suffers a loss as long as the man is so employed. Either way, there is a cost penalty that must be assessed against someone.

Some idea of the serious impact of industrial injuries on society and production output can be gained from a review of the U. S. Department of Labor statistical reports. One report indicates that although there have been substantial reductions in industrial injuries since the inception of organized safety programs, there are still about 2,000,000 disabilities, including 15,000 fatalities and 84,000 permanent disabilities, in all classes of employment each year. This number of injuries will result on the average in the loss of about 41,000,000 man-days of work during the year—which is equivalent to a loss from the labor force of 137,000 full-time workers. When additional allowance is made for the future effects on our economy of deaths and permanent physical impairments, the loss in total economic time amounts to about 206,000,000 man-days. This is equivalent to a year's full-time employment of nearly 690,000 workers.

After workmen's compensation laws were enacted starting in 1910, informed and progressive industrial management realized that the payment of insurance premiums or costs under a self-insurer's permit represented a large drain on profits. Steel, mining, and oil companies were the first to make progress in the prevention of accidents and to profit by the lower injury costs secured. Through a simple program of preventing contact with moving machinery and installing guard rails at elevated workplaces to prevent falls, substantial reductions in the incidence of injury were made. However, when a level about 25 per cent below the old rate was reached, it was found impossible to reduce the rate further by means of physical safeguards. The reason was, and still is, that the human factors have the greatest influence on safety in industrial operations. These human factors include, in their order of importance, the attitude of management regarding safety in company operations, the quality of supervision the worker receives, the worker's attitude toward his employing company and its employee relations policies and practices, and the skill or training that regulate the worker's actions on the job.

As time went on, the compensation benefits provided for the injured worker were increased by law, and medical and hospital expenses doubled and trebled. Progressive management, faced with continued increases in workmen injury costs in spite of all the safeguarding that was done, realized that more planning, better organization, and more intelligent research were needed if accidents were to be prevented. The larger companies have been most aware of this need. Consequently, as reported by the U. S. Department of Labor, the accident rates and injury costs in the larger companies are substantially lower than in the medium-sized and smaller companies.

2. NEED FOR ORGANIZATION AND PLANNING THE PROGRAM

The need for planning, the need for intelligent administration of a safety program, and the need for an adequate organization to carry on the many parts of that program are greater today than they were early in the history of organized accident-prevention programs. There are many reasons for this. There has been a tremendous industrial expan-

sion, and production processes are more complicated and diversified. Almost all states have adopted restrictive safety orders and laws regulating design, type, and operation of industrial equipment. Organized labor has entered the field of safety and has demanded better protection for its members while on the job. This section deals with the fundamentals, organization, administration, practices, and procedural details of accident-prevention programs that have proved effective and economical in industry over a period of many years. If followed, success in reducing the frequency of accidents and their attendant injuries is assured. The results are lower production costs, gained not only through reduction in injury, compensation, and medical costs, but also through the greater efficiency of operations and production per man that comes from the better morale of workers in a plant that has a reputation as a safe working place. This axiom applies to any plant and any company, regardless of size or type of product.

In any industry, the program to prevent accidents or to reduce them to a reasonable minimum and the organization to carry on that program must be intelligently planned. Even in the smallest of companies, where the responsibilities of developing production practices, maintaining equipment, purchasing, employee relations, and safety rest in the hands of a single man, the safety program must be planned. The pattern differs from that of a large company mainly in the number of people needed to carry it on. With the average cost of compensation insurance premiums for operating and maintenance personnel ranging from about 2 per cent of payroll in manufacturing industries to 10 per cent and higher in more hazardous industries, there should be no question of the value of a program that will reduce the accident experience and the cost of insurance premiums. Since the inception of organized safety in American industry, no safety program intelligently planned and diligently executed has failed to produce a good accident experience. This result, however, has been secured only after consideration of the many factors and actions outlined below.

Safety is not an entity separate from production. It is not a field of industry set apart for the accident-prevention specialist. A safety program must be coordinated and integrated with the production program. The same executives who are responsible for low production costs and high production efficiency are responsible for carrying on the accident-prevention program. If the firm employs a safety engineer or a corps of safety engineers, they should be in a staff capacity and their only authority should be to advise the executives and lower supervisors on problems encountered in providing safe working places and promoting safe practices. They should have no authority to issue orders to workmen or supervisors. A safety engineer is responsible only for the quality and the reliability of the service, advice, and assistance that he gives to line management. As in the case of other staff specialists, such as design engineers, doctors, and purchasing agents, a safety engineer must be sure that the advice he gives is sound and is based on the best known and most thoroughly explored theories and practices.

3. FUNDAMENTALS OF SUCCESSFUL ACCIDENT PREVENTION

Success in preventing needless accidents and their attendant personal injuries requires no complicated system of policing and controls nor any involved scientific knowledge. There are, however, certain premises or fundamentals that must be accepted by industrial management and that, once accepted, must be continually emphasized and filtered down from the top of the organization to every level of management and supervision and to every job performed. The degree of success is dependent upon the degree to which these principles are *sincerely accepted and actively promoted* by management. The principles that must be accepted to attain success in keeping accidents in industry at a reason-

able level and that are accepted by those people in charge of American industry who have been successful in reaching that goal are:

1. There must be a sincere desire by management to have an effective safety program. The attitude of management will be reflected down through supervision to every job.

2. Participation must be so evident as to leave no doubt in the minds of subordinates about the attitude of management. There is a vast difference in the accomplishments of an accident-control program in which management is visibly active and one in which there is passive acceptance of the idea but no active participation readily apparent to the working force.

3. The fact must be accepted that to prevent accidents money must be spent to provide safeguards, to plan and design safe operating processes and procedures, and to staff an adequate organization to assist line supervisors in carrying out the safety policies that management has established. Experience has proved that every dollar intelligently spent on safety has returned big dividends. This type of spending should be given the same serious consideration that is given requests for funds to replace inefficient or outmoded production equipment and processes. Haphazard procedures and obvious tolerance of unsafe practices are also outmoded and inefficient in modern industry. It should be realized that supplying money to provide mechanical safeguards, good lighting, good ventilation, good safety training, and instruction for workers and supervisors is not so much an indication of leniency by management as it is a necessity—a "must" in efficient industrial production practices.

4. There must be an acceptance of the principle that the safety program is necessarily a part of the production process program. Therefore, the same executives who are charged with the responsibilities of developing and directing efficient production methods must be held responsible for the administration of the safety program. The safety engineers are their staff advisers who assist them in meeting their accident-control responsibilities.

5. Top management should put the accident-control program and the safety-engineer staff on the same plane in the organization of the company as other staff functions, such as engineering, medical, industrial relations, accounting, purchasing, and cost control. As a matter of fact, with the exception of the accounting function, the accident-control program is an adjunct to the activities of all the other staff units mentioned and assists them in carrying out their functions.

4. ENGINEERING DESIGN OF EQUIPMENT AND PROCESSES

The basic goal of the design engineer during any project is to originate a structurally sound piece of equipment or process with operational perfection and economic justification. But there is also an ultimate goal. An engineering project must not be considered complete unless the following specifications are fulfilled in addition to the basic goal:

1. Provision of sufficient room and proper equipment for the safe storage and handling of materials.

2. Location of machines and equipment not only from an operating standpoint, but also to allow a maximum degree of safety to the installation and personnel during maintenance operations.

3. Location and physical guarding of installations to reduce or avoid hazards.

4. Installation of facilities, including walkways, stairways, platforms, and so forth, to provide safe access to otherwise inaccessible locations during operation, maintenance, and emergency conditions.

5. Consideration of fire-prevention facilities.

6. Consideration of employee facilities in the form of lunchrooms, washrooms, change rooms, toilet facilities, and offices, including the adequacy of lighting, heating, cooling, and ventilating. (See Section 8, Art. 5.5.6.)

It is evident then that all phases of a project design cannot be completed with only a basic goal. If the above specifica-

tions are not included during the design stage, certainly neither an economic justification nor a design engineer's professional obligation has been fulfilled.

The safety engineer or representative can play an important role in liaison with the project engineer during the design stage of a project. In the performance of this work, the functions of the safety engineer may be summarized as follows:

1. Advise project engineers of personnel and equipment safety requirements as early as possible in the course of design work to avoid costly revisions later in the design program or during construction.

2. Assist project engineers in complying with applicable personnel safety codes and regulations pertinent to current project work.

3. Be thoroughly informed concerning current designs in progress in the engineering department so that all safety questions that arise may be comprehensively and quickly answered.

4. Assist project engineers in obtaining operating organizations' approval involving safety in designs as early as practicable in the course of a project to avoid costly revisions. This may be accomplished by assisting the engineer to interpret codes and regulations as they relate to specific designs and by discussing current designs with representatives of the operating organization to assure agreement of interpretations.

5. Assist project engineers by making analyses to determine economic justification of changes or inclusions in designs or construction recommended for safety reasons.

In carrying out these functions, the safety engineer should act only in an advisory staff category and should not assume any of the basic responsibilities for design. On his own initiative, the safety engineer should spend sufficient time in the engineering organization to keep abreast of design progress on current projects. In effect, he serves as liaison between the engineering organization project engineers, representatives of the operating organizations affected, and his own organization. The safety engineer should therefore continually work with operating organizations to become thoroughly acquainted with operating techniques that may affect design.

The project engineer should then magnify his basic goal to include the responsibility for personnel safety requirements in design. He should seek the advice and assistance of the safety engineer or representative. The safety department may help him by preparing a manual covering safety in designs. The purpose of this manual should be to assemble in convenient form information and pertinent designs so that preferred practices can be incorporated in all installations.

5. INCLUSION OF SAFETY IN WRITTEN OPERATING STANDARDS AND INSTRUCTIONS

Although continued vigilance and educational programs, along with safety in designs, are necessary to insure a successful safety program, we cannot be assured that human error will not interfere and cause serious consequence to both personnel and equipment. This is especially true of complex operations in plants or processes.

Airline and air force pilots, though highly trained, use check lists and written operating procedures so that they will not have to rely on memory or instinct. Similarly, in the operation of complex plants or installations where the slightest error in operating procedure may cause extensive damage to equipment and serious injury to personnel, operating standards or instructions should be a necessary part of routine operation. Operating personnel, maintenance personnel, and all others connected with the operation should be thoroughly familiar with these standards and instructions and should be required to use them.

Although the standard or instruction should explain the operation in its entirety, including charts, check lists, and so forth, specific safety items should be included to assure protection of personnel and equipment from designated haz-

ards. These items may include hazardous chemicals and their use, electrical hazards, rotating equipment, rescue procedures, protective clothing and equipment, and fire-prevention and fire-fighting procedures.

The following is a recommended form for operating standards. As an example, a power plant is used as the subject material, since this is a necessary part of many plants or installations, large and small.

In addition to a complete explanation and running check list as outlined below, charts and graphs for quick reference should be included for operators' use. For a power plant, such a chart might list the safe limits of temperature and pressure for all equipment.

This summary is merely an example of the type of material that can be used as an aid to operating personnel and maintenance crews in the safe performance of their duties. There are many ways to accomplish this purpose, but it is essential to fortify other phases of the

OPERATING STANDARD NO. ________

OPERATION OF ________________ POWER PLANT

Purpose	1. This standard prescribes the general procedure to be followed in the power generation at ________________ Power Plant.
	SAFETY
General Precautions	2. The detailed instructions contained in this standard are designed to promote Safety of Personnel and equipment and economy of operation in ________________ Power Plant. It is important to prevent sudden changes in boiler operating or electric generating conditions which will seriously affect their capacity to carry loads and maintain a constant supply of steam or electricity to meet demands. To prevent such conditions, follow the instructions provided in this standard.
Avoid Hazards	3. ____________
Rescue Work	4. ____________
Fire Apparatus	5. ____________
Gas Masks	6. Location and use.
Spills	7. ____________
Protective Goggles	8. ____________
Clothing	9. Care around rotating machinery, etc.
Hot Lines	10. ____________
Hot Water	11. ____________
Steam Leaks	12. ____________
Electrical	13. Avoid contact, etc.
	STEAM GENERATION
Boiler Water	14. Description of process, etc.
High Pressure Steam	15. ____________
Exhaust Steam	16. ____________
	Starting Cold Boiler
Inspection	17. ____________
Set Lines and Valves	18. ____________
Filling With Water	19. ____________
Hydrostatic Tests	20. ____________
	Firing the Boiler
Set Lines	21. ____________
Check Gas Supply	22. ____________

safety effort with a scheme of safety instructions and check charts to be included in operating standards that are guides to personnel in all plants, especially those with complex processes.

6. SPECIFICATIONS FOR SAFEGUARDING

Safeguarding of machines and workplaces in general is an important phase of accident prevention. Manufacturers of machines are now more cognizant of the practice of guarding moving parts. On many machines, self-lubricating or automatic lubricating devices are installed to reduce this hazard. However, it is essential that the user take steps to assure complete protection for his personnel. Working areas which are by location hazardous should be guarded to eliminate the dangers involved.

Specification for safeguarding all conditions is directly related to the design stage of a project and to the engineer responsible. (Refer to Specification No. 3, Art. 4.) In placing orders for machinery, equipment, and other material, the engineer can gain economical and operational, as well as mechanical, advantages by specifying that it be guarded in compliance with codes and standards.

6.1 TYPES OF GUARDS

When dangerous moving parts of machinery are remote from working areas or are located with reference to a structure so that accidental contact is not possible, they can be considered locationally guarded.

Otherwise, shield guards can be used to eliminate the possibility of accidental contact with the moving parts. For example, Fig. 11.1 shows a typical guard to protect against rotating couplings and keyways on shafts. Figure 11.2 depicts a typical guard for a belt and pulley installation that allows for lubrication of parts without removal of guard. This is extremely important, since many types of equipment must be lubricated in motion.

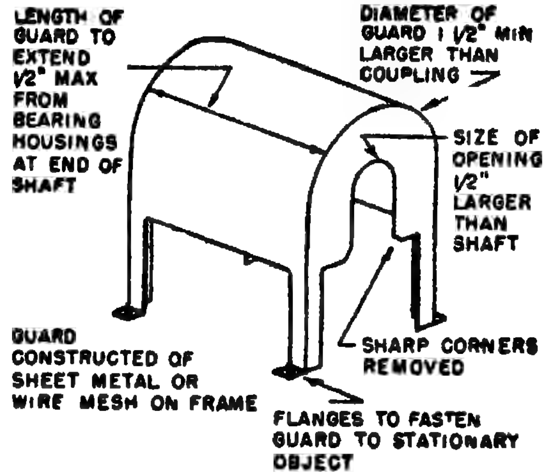


FIG. 11.1 TYPICAL COUPLING GUARD.

Another typical belt and pulley guard is shown in Fig. 11.3. For larger installations, the guard must extend to at least seven feet above the ground or platform level to give complete protection. Figure 11.4 shows one type of guard for gear mechanisms. The hinged installation provides easy access for lubrication and assures that the guard will always be in place.

There are many other types of mechanism involving hazardous moving parts that it is necessary to safeguard. Such installations as power conveyors, fans on internal-combustion engines, counterweights, and flywheels are a few hazards to consider. Surfaces hot enough to burn animal tissue on momentary contact should be guarded by insulation or made inaccessible by barricade. Adequate

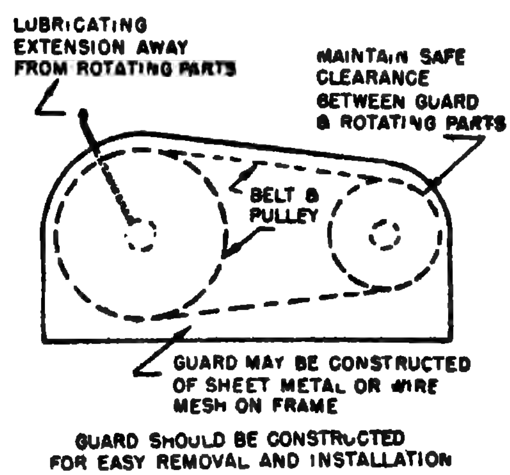


FIG. 11.2 TYPICAL BELT AND PULLEY GUARD.

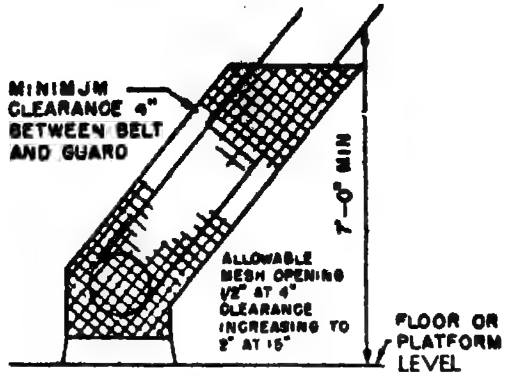


FIG. **11.3** TYPICAL INCLINED BELT AND PULLEY GUARD.

guards should be placed around fittings, such as flanges and valves, in which corrosive chemicals are handled under pressure. Figure 11.5 shows such a guard.

6.2 MEANS OF ACCESS

Operating and maintenance areas that are located in permanently inaccessible locations and that require ordinary operating attention and/or frequent repair, adjustment, or handling, should be provided with platforms, maintenance runways, walkways, or ramps that are accessible by means of ladders or, if possible, by stairways. In choosing between a ladder and a stairway, the following points should be considered:

1. Number of times used per day.
2. Necessity for carrying tools or equipment when ascending or descending.

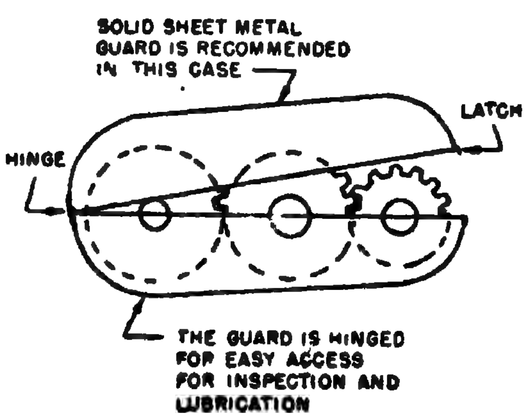


FIG. **11.4** TYPICAL GUARD FOR GEAR MECHANISMS.

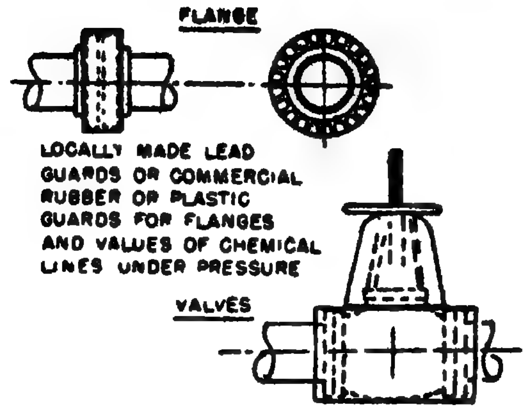


FIG. **11.5** TYPICAL CHEMICAL GUARD FOR FLANGES AND VALVES.

3. Age and physical condition of personnel who will use the installation.

Every stairway with four or more treads should have a handrail. Figure 11.6 shows a typical stair railing, with

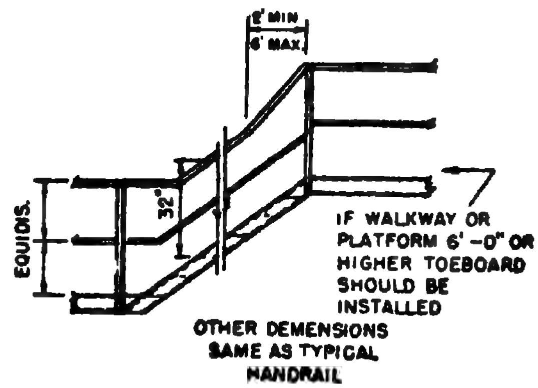


FIG. **11.6** TYPICAL STAIR RAILING.

recommended dimensions. Note that the stair railing ties in smoothly with the platform or landing handrail. Figure 11.7 depicts the typical handrail for platforms, walkways, runways, or ramps

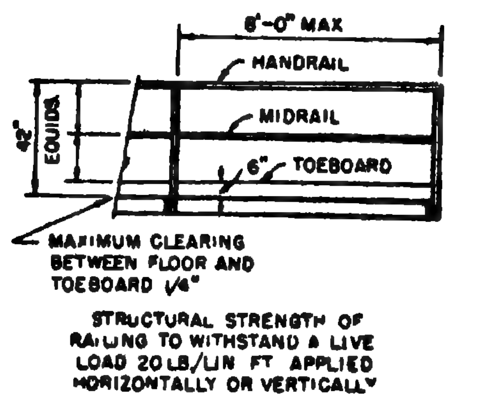


FIG. **11.7** TYPICAL HANDRAIL.

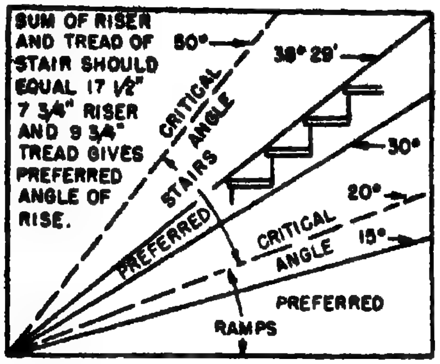


FIG. **11.8** PREFERRED SLOPES FOR STAIRS AND RAMPS.

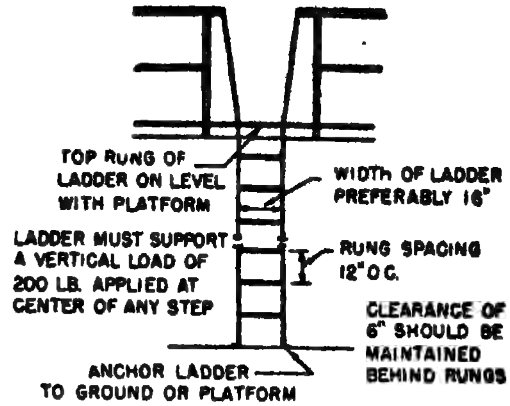


FIG. **11.10** TYPICAL FIXED LADDER.

which are four feet or more above the ground. The toe board is not required for elevations under six feet.

The preferred slope of stairways is shown in Fig. 11.8. All stairways on any one installation should have the same slope.

Ramps should be used as little as possible if stairways and a straight run of walkway can be used instead. Figure 11.8 indicates preferred slopes of ramps, and Fig. 11.9 shows a typical ramp with recommended dimensions.

Where stairways are not possible or practicable, fixed ladders should be used. Vertical ladders are recommended. Figure 11.10 shows a typical fixed ladder with opening to platform. This opening should be guarded with a drop bar or a chain guard attached to handrail.

Vertical fixed ladders over 30 feet in length or 30 feet or more above the ground should be supplied with a backscreen or ladder cage. Figure 11.11 depicts a typical ladder cage.

In addition to the structural phase of designing walkways, stairways, and platforms, the nonskid qualities of walking surfaces must be considered. Nonskid surfaces are especially important around equipment or installations exposed to oil, water, ice, or other slippery conditions. Any material that may become a hazard through normal wear and tear should be avoided for use in walkways.

7. ADDITIONAL ENGINEERING FACTORS IN SAFETY

Many safety-in-design features have been discussed that deal with the more common problems encountered in project design and operating and maintenance practices. The safety aspects of several other conditions require special handling. This section deals with these special conditions.

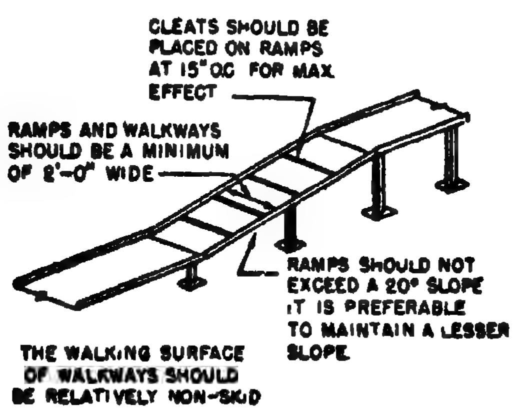


FIG. **11.9** TYPICAL RAMP.

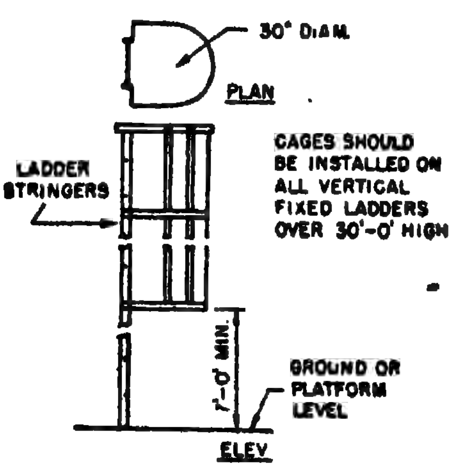


FIG. **11.11** TYPICAL LADDER CAGE.

7.1 ELECTRICAL

Only the basic requirements for safety in electrical designs are presented here. They must be supplemented by city, county, state, and national codes in force where designs are originated. Where the codes are not stringent, these basic requirements should govern.

All electrical materials, devices, and appliances used in electrical installations should be of an approved type listed or labeled by the Underwriters' Laboratories, U. S. Bureau of Standards, U. S. Bureau of Mines, or other institutions of recognized standing. When questions arise concerning material or equipment not approved by a specific organization, the safety engineer should be contacted for advice.

Bonding and grounding techniques should follow good practice to prevent hazard from static electricity, short circuits, and stray currents. The following practices are especially important.

1. Frames and all exposed metal parts of portable electric hand tools which do not carry current should be grounded.

2. Exposed, non-current-carrying metal parts of all fixed electrical equipment, such as motors, generators, and control equipment, should be permanently grounded when in hazardous locations; when equipment is within reach of a person who can make contact with any grounded surface or object; when equipment is supplied by metal-clad wiring; and when equipment is operated at more than 150 volts to ground.

3. The metal guards of portable lamps must be grounded with a three-conductor cord and two-pole, three-wire receptacle, unless the base and handle of the lamp are made of a non-conducting material.

There should be enough space around electrical equipment to allow ready and safe operation. This work space should not be less than two and a half feet. Around equipment such as switchboards and control panels, it should be increased as voltage ratings increase. Applicable codes should be closely followed in these instances.

Another important factor in the selection of equipment for electrical installations is the location involved. Locations can be divided into three classifications that should be included in the plant general engineering specifications for electrical equipment:

Type 1—Locations where hazardous concentrations of flammable vapors or gases, volatile liquids, continually suspended combustible dust, or easily ignitible fibers or materials are anticipated during normal operations.

Equipment required—Use equipment with *all* electrical parts enclosed in an enclosure capable of withstanding an internal explosion without igniting flammable vapors outside.

Type 2—Locations where these conditions may occur only as a result of abnormal conditions or equipment failure.

Equipment required — Equipment with arcing or sparking contacts must be enclosed in an enclosure capable of withstanding an internal explosion without igniting flammable vapors outside. Equipment which produces no sparks that will ignite explosive vapors under normal operating conditions can have general-purpose enclosures.

Type 3—Locations where there is little or no hazard from flammable vapors.

Equipment required—There are no restrictions regarding the use of sparking equipment in non-hazardous locations.

Clearances for supply conductors, guy wires, messenger wires, and trolley wires from the top surface of rails, buildings, thoroughfares, and other objects are essential for safe installations. It is recommended that Table 11.1 be followed in this case.

7.2 CHEMICAL

Although some chemicals are harmless, most of them are hazards to personnel safety and must be closely

TABLE 11.1 CLEARANCES FOR SUPPLY CONDUCTORS

Nature of clearance	Wire or conductor concerned					
	A Span wires (other than trolley span wires), overhead guys and messengers	B Communication conductors (incl. open wire, cables and service drops), supply service drops of 0-750 volts	C Trolley contact feeder and span wires, 0-5000 volts	D Supply conductors of 0-750 volts and supply cables	E Supply conductors and supply cables 750-20,000 volts	F Supply conductors and supply cables more than 20,000 volts
1. Crossing above tracks of railroads which transport or propose to transport freight cars (max. height 15 ft. 1 in.) where not operated by overhead contact wires.	25 feet	25 feet	22 feet	25 feet	28 feet	34 feet
2. Crossing or paralleling above tracks of railroads operated by overhead trolleys.	26 feet	26 feet	19 feet	27 feet	30 feet	34 feet
3. Crossing or along thoroughfares in urban districts or crossing thoroughfares in rural districts.	18 feet	18 feet	19 feet	20 feet	25 feet	30 feet
4. Above ground along thoroughfares in rural districts or across other areas capable of being traversed by vehicles or agricultural equipment.	15 feet	15 feet	19 feet	16 feet	25 feet	30 feet
5. Above ground in areas accessible to pedestrians only.	7 feet	10 feet	19 feet	12 feet	17 feet	25 feet
6. Vertical clearance above buildings and bridges (or other structures, which do not ordinarily support conductors and on which men can walk) whether attached or unattached.	8 feet	8 feet	8 feet	8 feet	12 feet	12 feet
7. Horizontal clearance of conductor from buildings (except generating and substations), bridges or other structures (upon which men may work) where such conductor is not attached thereto.	—	3 feet	3 feet	3 feet	6 feet	6 feet
8. Distance of conductor from center line of pole, whether attached or unattached.	—	15 inches	15 inches	15 inches	15 or 18 in.	18 inches
9. Distance of conductor from surface of pole, crossarm or other overhead line structure upon which it is supported, providing it complies with Item 8 above.	—	3 inches	3 inches	3 inches	3 inches	—

guarded. An injury caused by chemical exposure can be extremely serious.

Protection against chemical exposure or contact by personnel can be accomplished to a great degree in the design stage of an installation. Further protection in the form of protective clothing, respiratory protective devices, or emergency devices is essential. (See Fig. 11.12.)

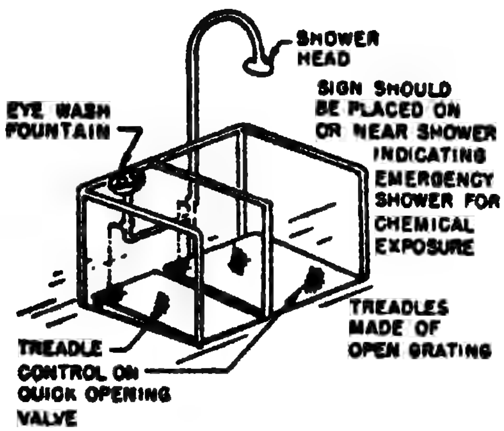


FIG. 11.12 TYPICAL EMERGENCY SHOWER AND EYE WASH FOUNTAIN.

Proper guarding of equipment will eliminate most accidental contacts with hazardous chemicals. In preparing the specifications for equipment that will handle corrosive chemicals, the following factors should be thoroughly considered:

1. Equipment or pipe lines that are to handle corrosive chemicals should be resistant to the corrosive action.

2. Where it is necessary to provide valves, flanges, or other fittings in lines handling corrosive chemicals, lead guards locally fabricated or commercial rubber or plastic guards should be considered for installation on the fittings. Where possible, use tongue and groove fittings. See Fig. 11.5 for typical lead guard installations.

3. Pumps, siphons, or other equipment should be guarded. The liquid end of such pumps should be entirely enclosed.

4. Special chemical-resistant packings must be used in valves, pump glands, and so forth, as added protection.

5. Sampling devices for removing samples of corrosive chemicals from closed systems should be of special design to prevent splashing and dripping.

Identification of chemicals in equipment is an essential part of providing safe operating facilities in plants or installations. All vessels or equipment in which corrosive chemicals are stored or used should be identified with durable signs that give the name of the chemical and a warning, such as "Caution." This not only aids operators in their performance but also provides additional warning to maintenance personnel working with this equipment. Pipe lines that carry corrosive chemicals should be identified by stenciling the name of the commodity and the direction of flow on the line or by tagging the line. Since yellow is generally considered a "caution color," a yellow background with black lettering is recommended for these identifying signs. The marking of lines at the plot limit of plants or installations is especially important to assure correct identification by operators and maintenance personnel of where the line enters the operating area.

Storage of corrosive chemicals must be carried out with systematic care. All containers must be plainly labeled, and storage areas must be plainly designated by signs. Small containers of corrosive chemicals should not be stored on high storage shelves, and all storage areas should be cool, well ventilated, and remote from acute fire hazards. Incompatible chemicals must never be stored and handled so that contact is possible. For example:

1. Never store acetone next to concentrated nitric and sulfuric acid mixtures.

2. Never store copper near acetylene or hydrogen peroxide.

3. Isolate fluorine from everything.

4. Never store sulfuric acid near chlorates, perchlorates, or permanganates.

In designing storage facilities for corrosive chemicals, these problems should be thoroughly considered.

In plants or installations where cor-

rosive chemicals are used to a great degree, protective clothing is an essential part of the operating and maintenance personnel equipment. Such equipment must be maintained in perfect order and should be cleaned and sterilized after each wearing.

7.3 AIR POLLUTION

When dusts, mists, fumes, gases, or vapors are produced in quantities that may be harmful to personnel, control should be maintained by exhaust ventilation systems at the point of generation. These are essential when general ventilation proves ineffective or when elimination or prevention of the source of pollution is not possible or practicable.

The exhaust system must be designed and operated to maintain a volume and velocity of exhaust air to convey all impurities to points of safe disposal. The system must not draw the impurities through the breathing zone of workmen and must not exhaust them into working places where they can cause harmful exposure.

Stacks from equipment that produces quantities of smoke or harmful vapors should be located so that harmful quantities are not spread over working areas and public places. Where it is impossible to eliminate this condition by location, smoke eliminators should be designed into the equipment.

Where air pollution conditions cannot be entirely eliminated from working areas, personnel should be required to wear respiratory protective equipment. Information on the maximum safe concentration of air contaminants can be obtained from any good publication on noxious gases and vapors.

7.4 WELDING

The many types of welding operations create numerous hazards to personnel and equipment unless proper safeguards are taken. For instance, the harmful light rays produced by welding flames and arcs may seriously injure the eyes or burn the skin. Similarly, poisonous fumes and gases produced in welding operations may cause serious illness. Because of the many possibilities for injury to personnel and for damage to equipment in welding operations, it is essential that safe practices, regulations, and explicit operating standards be issued and be strictly observed.

Of primary importance is the strict adherence to a standard that permits only authorized personnel to perform welding operations and that requires all personnel involved to use suitable personal protective clothing, such as gloves and aprons or shields. Goggles must be carefully selected on the basis of lens shade to give proper protection for the welding operation involved.

In areas designated as welding operating locations, ventilation must be adequate to carry away harmful concentrations of fumes that may be generated. In most cases, local exhaust ventilation at the point of welding is necessary, especially in confined spaces.

Welding operating areas must not be located near flammable or explosive substances. All flammable material should be removed from the immediate vicinity and wooden floors or walls should be avoided or adequately protected by fire-resistant shields. Tanks, cylinders, or other containers must never be welded until it has been assured that they do not contain, or have not contained, flammable or explosive substances. Since the heat of welding may cause a sufficient increase in pressure to rupture or explode an unvented container, sealed containers must be vented.

In *oxyacetylene welding* the oxygen, acetylene, and the flame require special handling to prevent injury to personnel or damage to equipment. The following precautions should be a required standard:

1. Grease or oil must not be allowed to come in contact with welding equipment.

2. Acetylene should not be used from

cylinders at pressures in excess of 15 pounds per square inch.

3. All cylinders should be provided with protective caps when not in use.

4. Cylinder valves must be immediately accessible when cylinders are in use to permit quick shut-off in emergency.

5. Hose must be protected from mechanical damage and must be periodically inspected for leaks by being submerged in water.

6. Torch must not be left burning when not in use and its valve should be shut when not in use.

Electric arc welding presents the additional hazard of electrical contact and fire from electrical sources. The precautions necessary for electric welding can be listed as follows:

1. Shields of curtains or screens must be provided around arc-welding locations to prevent injury to eyes of personnel in surrounding area.

2. Circuits must be checked only when system is dead.

3. The polarity and rotary switches must not be operated while equipment is under load.

4. Motor generator and other electric welding apparatus must be provided with adequate ground.

5. Cables must be protected from mechanical damage and any loose connections or defective electrode holders must be replaced.

6. Repairs must be made on this type of equipment by qualified electrical maintenance personnel.

7.5 GENERAL

Many other factors concerning engineering relationships to safety must be considered in an active accident-prevention program. In general, if all phases of a design or operation are considered, operating perfection will be assured and the plant will be safely operated and maintained.

8. SPECIFICATIONS FOR PERSONAL PROTECTIVE EQUIPMENT

Many hazards to workmen cannot be removed or eliminated. Therefore, in order to avoid injury, the workmen must use personal protective equipment such as goggles, respirators, and safety hats. Strict supervision and sometimes discipline is necessary to get employees to wear protective equipment.

Many brands of personal protective equipment are available, but not all of them are made in accordance with the standards set by such agencies as the Bureau of Standards, Bureau of Mines, and American Standards Association. These organizations determine the specifications to which protective equipment should be made and, in some instances, test the devices and issue specific approvals. Only personal protective equipment that meets the requirements of these standards should be used.

In order to determine which equipment is satisfactory, the purchasing agent, those who initiate requisitions, should be provided with a guide. This guide should be issued by the safety department and should be kept up to date in order to take advantage of new devices that are made available. The safety department should determine the proper standard and should list several brands or styles of equipment that meet the standard. The purchasing agent should buy only the approved types or brands.

8.1 EYE PROTECTION

Protection for the eyes is one of the most important of the personal safety devices. There are many types of goggles available, and care should be taken to assure that the right type is used for a particular hazard. Hardened lenses are made in accordance with standards set up by the National Bureau of Standards.

Cup-type goggles protect the eyes

from all angles and should be used where complete protection from heavy flying particles is needed—for example, in riveting, chipping, grinding, and heavy hammering. They are made in two general styles, one of which is for use as a cover goggle worn over corrective spectacles. The frames are shaped and vented to accommodate such hazards as dust, heavy particles, or chemicals.

Spectacle-type safety goggles can be used by shop men and other workers who require protection from light flying particles. These goggles provide protection from particles coming from the front and can be obtained with side shields to protect against particles coming from the side. They come in a full range of sizes and can be fitted in much the same manner as corrective spectacles.

For those who must wear corrective spectacles and need eye protection during their work, it is possible to have the individual's prescription ground in hardened safety lenses. These provide full-time protection and in many jobs eliminate the need for the heavier type of goggle normally used over prescription spectacles. Many employers assist their employees in obtaining these prescription safety spectacles by paying a portion of the cost.

Both gas and electric welding require special eye protection to guard against the effects of the ultraviolet and infrared rays. The lenses of the goggles or welding helmets are made in various shades required for protection against rays. The filtering qualities for each shade are determined by the specifications set up by the National Bureau of Standards.

8.2 RESPIRATORY PROTECTION

Various types of protection against the breathing of harmful dust, fumes, or gases are available. The use of respiratory equipment should be regarded in most cases as emergency protection against casual or relatively brief exposure. Certain work, such as that done by sand blasters, may require continuous use of the equipment. However, every effort should be made to reduce the concentration of gases, vapors, or dust to such a level that the air is safe to breathe for eight-hour periods.

When the hazard cannot be completely eliminated, one of the following types of respiratory equipment should be used. The U. S. Bureau of Mines has set up rigid standards and tests for respiratory protective equipment and issues certificates of approval to manufacturers meeting these standards. Use of such approved equipment assures full protection when the equipment is properly used for the hazard involved.

Mechanical-filter respirators are designed to remove "particulate" matter such as dust, fumes, and mists from inhaled air by mechanical filtration. They will not provide protection against vapors or an atmosphere deficient in oxygen.

Chemical cartridge respirators are designed for respiratory protection against organic vapors which are not immediately dangerous to life but which may produce discomfort, a chronic type of affliction or poisoning after repeated exposure, or mild acute symptoms after prolonged exposure. The Bureau of Mines approves this type of respirator for protection in atmospheres containing not more than one-tenth of one per cent organic vapors by volume (1,000 parts per million) which are not immediately dangerous to life. A partial list of such vapors includes acetone, alcohol, amyl acetate, benzine, benzol, carbon disulphide, carbon tetrachloride, chloroform, creosote, ether, hexane, lacquer, naphtha, pentane, phenol, toluene, trichlorethylene, and turpentine.

Canister-type gas masks are used for protection against harmful gases, vapors, fumes, mists, dusts, or smokes. All the air is drawn through a canister which filters, absorbs, neutralizes, or catalyzes limited amounts of harmful materials. Since the canister serves only to remove

gases from the air and will not supply oxygen, this type of gas mask will not protect against suffocation if worn in atmospheres deficient in oxygen. Canisters are provided for use as protection against specific materials in concentrations of not more than 2 per cent (3 per cent in case of ammonia). Canister-type gas masks are intended for use in the open and should not be worn as protection inside tanks or other confined places where higher concentrations may be encountered.

Supplied-air respirators provide protection by conveying respirable air to the wearer through hoses, tubes, piping systems, air holders, or combinations of these. Various types of hose masks, air-line respirators, compressed-air respirators, self-contained breathing apparatus, sand blast helmets, and hoods are used for protection against specific hazards. When the air is supplied by mechanical compressors, purifiers should be provided in the line to remove carbon monoxide, which may be generated if the compressors are not in good mechanical condition or if they have their air intakes near engine exhausts. Only hose masks with positive pressure blowers or self-contained breathing apparatus should be used in immediately harmful atmospheres or in atmospheres from which the wearer could not escape without the aid of the equipment.

8.3 HEAD AND FACE PROTECTION

Safety hats have prevented many injuries, particularly in the construction industry. They should be worn by all workers exposed to falling objects. The objects need not be large to cause serious injury Small bolts and rivets have been known to fracture unprotected skulls.

Safety hats are made of metal and of glass, plastic, and other nonmetallic materials. So long as the hats comply with the test specifications of the National Bureau of Standards, the type to be used can be determined by factors of cost, weight, head-band suspension, color, and so forth. In some types of work, such as electrical work, the hats should be of nonmetallic material. Safety hats equipped with plastic visors provide eye and face protection as well as head protection.

Face shields provide satisfactory protection for certain types of hazards, such as small flying particles or splashes of liquids; however, they are not acceptable for most uses where safety goggles are required for eye protection, since the plastic shields will not withstand the impact of heavy, fast-flying objects. The shields are made of plastic of various thicknesses and degrees of scratch resistance. The shield should have a minimum thickness of 0.04 inches. Face shields are also available in green and other shades for protection against excessive light. The plastic material must not be of the type that is easily ignited or that burns rapidly.

For full protection of the head from such hazards as extreme heat and spray painting, hoods that cover the head are best. Many types are available for various kinds and degrees of hazard. For use in abrasive blasting work, the hoods must provide respirable air to the wearer while protecting his head and shoulders against impact and abrasion by the rebounding sand or shot used in the process. An air-supplied hood, an air-line respirator, or a mechanical-filter respirator may be used, depending on the degree of hazard. When sand-blasting operations are conducted in a room or enclosure, the operator and helpers should be protected with supplied-air equipment.

8.4 PROTECTIVE CLOTHING

Workers who handle hot objects, rough materials, or chemicals should wear gloves of the type made for the specific hazard involved. Usually, gloves are worn along with other body protection, such as aprons, coveralls, hoods, goggles, and shields, since the hazard often involves other parts of the body.

The American Standards Association publishes specifications for certain types of protective clothing, and these should be used whenever applicable. If no standard applies, or if the effect of the hazard on the protective material is not known, trials and tests should be made to ascertain that the material will actually provide satisfactory protection.

Safety shoes with protective toe-caps provide excellent protection against toe and foot injuries. They should be worn in any occupation where there is danger of objects falling or being dropped on the workers' toes. In order to encourage their use, many employers make these shoes available—sometimes at prices below cost. Safety shoes are made in many styles, from dress shoes to heavy-duty boots.

9. SAFETY INSPECTIONS

Safety inspections are important and fundamental in a planned accident-prevention program. Full success of the program cannot be realized if positive and determined efforts to discover hazardous situations are either ignored or carried on in an insincere manner. Safety inspections are too often confined to detecting unsafe physical conditions, such as lack of safeguards, ungrounded electrical equipment, and the like. Inspectors should be trained to observe work practices during an inspection tour, because 90 per cent of all accidents involve an unsafe personal act—some act that should not have occurred, or some action that should have been taken but was not.

Safety inspections should not become a "police action." Inspection plans that "point a finger" at someone are doomed to failure; once this type of program has been used, considerable time and effort are required to overcome the bad effects produced. A safety inspection should be a cooperative effort. It should use the various personal talents available, and should be aimed at improving the accident situation by finding and correcting unsafe conditions and educating supervisors and workmen in safe work practices.

The line supervisor should make frequent inspections of his area, and should welcome inspections from others, since it is difficult for one person to see or notice everything about an area. He is responsible for the safe working conditions in his area or department. When safety inspections are made by someone other than the supervisor of the area, as they sometimes are, the line supervisor must not feel that the inspection party has assumed his responsibilities or that his prerogatives have in any way been challenged. Inspections help protect the line supervisor from reprimands that may come from his superiors if an accident occurs because of sub-standard conditions. Although this may seem at first glance to be a secondary reason for inspections, it is all-important to the supervisor, since the existence of sub-standard conditions is sometimes a reflection on his ability.

Several different methods are used to set up procedures or guides for conducting safety inspections. One plan that has been successful is outlined in the following paragraphs. In considering safety inspections, basic safety can be reduced to eight simple general items: five concerning conditions to be checked and three concerning actions that can be taken to remedy the hazardous conditions found.

The five general categories to be inspected for unsafe conditions include the work area, the material handled, the hand tools used, the machines used, and personal protective equipment required. The brief breakdown of the five categories that follows can be enlarged upon as supervisors gain experience in planned inspections. Printed on a check list, they serve as effective reminders for members of an inspection party. This breakdown lists the items to be observed for unsafe physical conditions and unsafe practices or personal acts.

Work Area

1. Housekeeping
2. Job lay-out

3. Aisles and exits
4. Stairs, ramps, and ladders
5. Floors and other working levels

Materials Handled

1. Piling and storage
2. Loading and unloading
3. Racks, platforms, and bins
4. Hand signals
5. Cranes, chains, hoists, slings, etc.

Hand Tools

1. Condition of hand tools
2. Improper use of hand tools
3. Inspection and maintenance of hand tools
4. Difficulties, if any, in securing hand tools
5. Housekeeping as related to hand tools

Machines Used

1. Lack of physical safeguards
2. Condition of physical safeguards
3. Actual protection afforded by safeguards
4. Location of controls
5. Mechanical condition of machinery and equipment as it affects safety

Personal Protective Equipment

1. Goggles and other eye protection
2. Respirators, fresh-air hose, masks, etc.
3. Equipment provided but not used
4. Shoes, hats, gloves, special clothing
5. Difficulties, if any, in securing equipment

The **three actions** that can be taken when an unsafe personal act or unsafe condition is noted are:

1. Remove the hazard.

2. Protect the worker against the hazard.

3. Develop safe practices to avoid injury from the hazard.

Safety inspections are useless in the accident-prevention program unless immediate and positive action is taken to correct the conditions revealed. If the individual making the inspection has the necessary authority, he should take immediate action personally. If the correction requires authority not possessed by the individual making the inspection, he should make immediate recommendations to such authority.

10. INVESTIGATION OF ACCIDENTS

10.1 ACCIDENT INVESTIGATIONS

Successful accident-prevention programs include three fundamental activities: inspection of working areas, thorough study of all operating methods and practices, and education and instruction of employees to minimize human errors. Because of our human failings, accidents often occur even when these three functions have been stressed heavily. It is then that a fourth activity, although a secondary defense against accidents, becomes a vitally important function of the accident-prevention program. This activity is a thorough, impartial, and honest investigation of all the circumstances leading up to an accident.

The primary purpose of accident investigations is to determine the true basic cause of the accident for the express purpose of taking remedial action to prevent a recurrence and to remedy the weakness in one or more of the safety-program activities. Never should investigations be conducted for the purpose of placing "blame." Investigations held for this purpose will do irreparable damage to the program. With the discovery of weak spots in the three previously mentioned fundamental activities, action can be taken to bolster this phase of the program.

In order to obtain a true picture of what actually occurred, investigations should be held without delay. Delay often results in failure to detect the true basic cause of the accident. Immediate investigations allow for first-hand observance of the condition of the work area and tools, and, most important, they help to eliminate "colored" stories told by witnesses. A witness can see just so much as an accident occurs, and he is likely to become curious about what else happened. Being human, he has a natural desire to get the complete story—and he usually gets his information from others. Then he draws his own conclusions on the cause of the accident.

In delayed investigations, the witness sometimes gives information based not wholly on what he saw, but rather on the conclusion he has made on the cause. Such evidence could lead to the selection of an improper basic cause that would reduce the value of the investigation.

The line supervisor is best qualified to investigate accidents because he knows the situation that resulted in the accident. He is closest to all the job conditions, such as the purpose of the job, correct job procedures, equipment and materials used, and the working conditions, and, of vital importance, he knows the employees. This knowledge fits him to arrive at the correct basic cause of the accident. Other people, such as a safety engineer, can help him conduct the investigation, but the line supervisor should not feel that his responsibility has been assumed by the other party. Committee investigations often prove to be of benefit. The line supervisor should, of course, be a member of the committee. This assignment proves to be a medium of education for the foreman, especially if his superior is also a committeeman. Having higher management represented on the investigating committee is beneficial in two ways: It allows management a chance to become better acquainted with conditions in the field, and it is visual proof to the employees that management has their interest at heart.

10.2 INVESTIGATION PROCEDURES

Of the various procedures in use, one that has proved itself is briefly submitted in the following paragraphs for use as a guide.

10.2.1 Care for the injured. After getting safely to the accident scene, the investigator's first concern should be to see that the injured person is properly cared for. He should apply first aid if necessary and should arrange for immediate medical and ambulance service.

10.2.2 Interview the injured. If the injured person's physical and mental condition permits, he should be interviewed on the details of what he was doing and the sequence of events leading up to the accident. If he is not in condition to be questioned, he should be contacted later as soon as his condition permits.

10.2.3 Interview the witnesses. Each witness should be interviewed in detail to obtain his version of all events leading up to the accident. Any discrepancies found in comparing witnesses' accounts of what happened should be immediately investigated to find the true facts.

10.2.4 Notice the details of the work area. All details of the work area, such as position of tools, lines, equipment, housekeeping, and unusual conditions, should be recorded.

10.2.5 Make detailed sketches if necessary. If details are complicated, sketches often make the picture of what happened stand out much better. For reports, sketches "paint the picture" more easily than words. Photographs often help in this respect.

10.2.6 Draw conclusions. From the detailed information produced by the investigation, conclusions can be reached. If they are derived in the proper manner, the basic cause of the accident can be selected without guesswork.

10.2.7 Make recommendations. From the basic cause and the facts obtained from the investigation, recommendations should be made on how to prevent a recurrence of a similar accident and on the action to be taken to strengthen the weak points in the three fundamental activities of the accident-prevention program. For educational purposes, a review of the accident, along with conclusions and recommendations, should be made in detail for all members of the crew involved in the accident and for any other crews doing similar work.

10.2.8 Submit written report. Reports will vary in make-up with the legal requirements and the desires of higher management. One type of report that has proved effective (see Fig. 11.13) gives a brief description of the accident, along with other information on the front side to meet legal requirements. The reverse side of the report provides

space for the basic cause selected, reasons for its selection, and recommendations, which should be filled in by the line supervisor.

This report provides a compact statement of details for review by higher executives as it passes up through channels. Experience has proved that this type of form, especially the requirement that the supervisor select and explain a basic cause, forces the supervisor to give more thought to the real causes of accidents instead of passing them off as an act of carelessness on the part of the

FIG. **11.13** TYPICAL ACCIDENT REPORT.

EMPLOYER'S REPORT OF INDUSTRIAL INJURY

DO NOT WRITE IN HERE
NO.

Every work injury to an employee which causes disability lasting longer than the day of the injury or which requires medical services other than first aid treatment must be reported within five days after the injury. If the injury results in death, a report must be made by telephone or telegraph to the Home Office not later than 24 hours after death.

I. EMPLOYER

1. Name (Give name under which concern does business)
2. Office address (No. and Street) (City or Town)
3. Nature of business

II. INJURED EMPLOYEE

4. Name Service Date Immediate Supervisor
5. Address (No. and Street) (City or Town)
6. Age 7. Sex: Check (✓) Male Female 8. Check (✓) Married Single
9. Number of hours worked per day per week Number of days worked per week
10. Wages: $ per Average weekly wages: $
11. If board, lodging or commissions, furnished in addition to wages, give estimated value per month $

III. ACCIDENT

12. (a) Place of accident (No. and Street) (City or Town) (County)
(b) If injured in connection with Joint Operations, give name of operation
13. On employer's premises (Yes or No) If answer is yes, give specific location
14. Department
15. Date of accident 16. Hour of day A.M./P.M. 17. Did injury result in disability beyond day of accident? (Yes or No) 18. If yes, give date last worked. 19. Was injured paid in full for this day? (Yes or No) 20. If injured in a mine, check (✓) accident location: Surface Mill Underground Shaft
Give names of witnesses

IV. CAUSE OF ACCIDENT

21. Occupation (job title) 22. How long employed by you at this occupation? Check (✓) less than 6 months; 6 months to 2 years; over 2 years 23. What was employee doing when accident occurred? (Describe briefly, such as loading truck, operating drill press, shoveling dirt, walking down stairs, etc.)
24. How did the accident happen? (Describe fully, stating whether the injured person fell, was struck, etc.; give all factors contributing to accident. Use other side of report for additional space.)
25. What machine, tool, substance, or object was most closely connected with the accident? (Name the specific machine, tool, appliance, gas, liquid, etc., involved)
26. If mechanical apparatus or vehicle, what part of it? (State if gears, pulley, motor, etc.)
27. Were mechanical guards, or other safeguards provided? (Yes or No) 28. Was injured using them? (Yes or No)
29. What do you recommend for preventing this type of accident? (State the specific preventive measures that can be taken by employer and workers. Do not say "by being more careful." Specify what should or should not be done.)

V. NATURE OF INJURY AND PART OF BODY AFFECTED

30. (Describe in detail the nature of the injury and the part of the body affected. For example: amputation of right index finger at second joint, fracture of ribs, lead poisoning, dermatitis of left hand, etc.)
31. Name and address of physician
32. Name and address of hospital
33. Has employee returned to work? (Yes or No) 34. If yes, give date 35. At what wage? $ per
36. Did injury result in death? (Yes or No) 37. If yes, give date
38. In case of death, give name and address of nearest relative

DEPT'S USE
Signed by (Manager or Superintendent)
Div. or Dist.
Date

SAFETY DIV. USE
Signed by
Official Position
Date

Filing of this report is not an admission of liability. "... No report of injury required to be filed by an employer or an insurer by this chapter shall be admissible as evidence in any adversary proceeding before the Industrial Accident Commission." Labor Code, Section 6413.

(COMPLETE REVERSE SIDE OF FORM FOR ALL ACCIDENTS)

DO NOT WRITE IN THIS COLUMN
Case No.
Employer No.
Industry
Age
Sex and Marital Status
Weekly Wage
County
Accident Date
Occupation
Accident Type
Agency
Agency Part
Mech. Defect
Unsafe Act
Personal Defect
Nature of Injury
Location
Extent of Injury
Insurance Carrier
Report Log
Coded By

Report of Investigation of Accidents

The Foreman, Branch Manager, Ship's Officer, Station Manager or other Supervisor under whom the injured worked shall investigate the accident at once and complete this side of the Form.

VI. Basic Cause of Accident. (Check only ONE of the following Basic Causes)

A—Management Responsibilities—Supervisory

- ☐ 1. No instructions given.
- ☐ 2 Incomplete instructions.
- ☐ 3 Rules, standards or instructions not enforced.
- ☐ 4. Personal Safety Devices not provided on job (Goggles, Safety Belts, Masks, Respirators, etc.)
- ☐ 5. Correct or safe tools or equipment not provided.
- ☐ 6 Inadequate inspection of equipment or jobs.
- ☐ 7 Improper method of doing work.
- ☐ 8 Poor job planning.
- ☐ 9 Too much rush.

B—Personal Action or Characteristic of Employee

- ☐ 1 Haste or short cuts
- ☐ 2 Equipment such as barrel trucks, skids, hoists, etc., provided but not used.
- ☐ 3 Goggles, respirators, masks, etc., provided but not used
- ☐ 4 Improper or unsafe tool or equipment used
- ☐ 5. Horseplay or fooling.
- ☐ 6 Instructions or rules disregarded.
- ☐ 7. Inattention.
- ☐ 8. Inexperience
- ☐ 9 Physical condition of employee.
- ☐ 10 Improper body position
- ☐ 11 Improper method of doing work
- ☐ 12 Action of fellow employee.
- ☐ 13. Improper clothing.

C—Management Responsibilities—Unsafe Equipment or Materials

- ☐ 1 Ineffectively guarded equipment
- ☐ 2 Unguarded equipment
- ☐ 3 Defective materials
- ☐ 4 Defective tools
- ☐ 5 Defective equipment (not motor vehicles)
- ☐ 6 Defective motor vehicle equipment
- ☐ 7 Improper type or poor design
- ☐ 8 Unsafe equipment or material of contractor, non-employee or customer.

D—Management Responsibilities—Unsafe Conditions

- ☐ 1 Poor light.
- ☐ 2 Poor ventilation.
- ☐ 3 Congestion.
- ☐ 4 Improper piling or storing
- ☐ 5 Exits or emergency escapes inadequate or not provided
- ☐ 6 Faculty layout of plant or facilities
- ☐ 7 Tools, equipment or materials scattered around
- ☐ 8 Slippery floors or other places.
- ☐ 9 Unsafe condition caused by contractor, non-employee or customer

VII. State In Detail Why You Selected the Above Basic Cause.

VIII. What Immediate Action did you take to prevent a recurrence and what do you suggest as Standard Practice to avoid Accidents of a Similar Nature?

(NOTE: Such answers as "Nothing," "More Precaution," "Be More Careful," cannot be accepted)

FOR SAFETY ENGINEER'S USE ONLY	
Type of Accident	
Nature of Work	
Accident Prevention Analysis	
Injury	

IX. ______________________ REPORT PREPARED BY ______________________ DATE __________ 19____

SUPT., DIST MGR., MASTER — FOREMAN, BRANCH MGR., STATION MGR., SHIP'S OFFICER

FIG. **11.13** (Continued)

injured worker. Also, because a review of the list of "supervisory responsibilities" suggests proper actions to the supervisor, he is likely to give more thought to things he could have done before the accident occurred.

When an accident results in very serious injuries or death, an additional detailed report including sketches, witnesses' statements, and other detailed information proves valuable. This should be made out for use by the employer in furthering his accident-prevention program.

11. SURVEYS OF SPECIFIC CONDITIONS, PROCESSES, SPECIAL HAZARDS, AND HEALTH CONDITIONS

Industrial processes produce various dusts, gases, and vapors. If such products or by-products are not controlled in closed systems or by removal, they may create a health hazard to workmen. When it is known or suspected that the concentration of air contaminants around process equipment is sufficient to create a hazard, a thorough survey of the equipment and operating practices should be made. Surveys are instituted whenever any condition in a plant develops an unexpected health or accident hazard.

A successful survey requires considerable preliminary work in order that the individuals making it will be thoroughly familiar with the general problem and that the employees involved will know why the condition is being studied. This latter factor is extremely important, since it eliminates speculation. When information is to be obtained from the workers, it is necessary to be completely above board with them to insure that they will give factual information.

The safety engineer is well qualified to conduct surveys of specific hazards and conditions that may be detrimental to health or that may lead to accidents. Since the workers and supervisors know that he is interested in their safety and health, he can usually get good cooperation during a survey whereas an unknown person might meet opposition. Furthermore, he is in a position to seek advice and assistance from the medical, chemical, operating, and engineering staffs. In some situations it may be desirable to call in an outside agency, such as the State Department of Health, U. S. Bureau of Mines, or an industrial agency that handles specific problems. The advantage of this method of surveying a problem is that such agencies are thoroughly familiar with specific hazards, have the necessary equipment for measurements and determinations, and have background and experience in handling similar problems. When an outside agency is used, it is important that someone, preferably the safety engineer, act as contact between the agency and the operating personnel.

Before any field work is done, the individual making a survey should become thoroughly familiar with the known information concerning the hazardous material, process, or equipment under study. This will keep him from doing unnecessary work that may already have been done, point the best way to investigate the problem, provide discussion information for talking to workers and supervisors, and instill confidence in the workers and supervisors that he will eventually reach the correct solution to the problem. The procedure to be followed in gathering information should be determined in advance and should be thoroughly planned in order that the necessary data can be obtained in the minimum of time. Equipment for making measurements, analyses, or determinations should be fully understood and tested in advance, so that the operator is familiar with all the details of its use. All employees are strongly interested in any conditions that may be detrimental to their personal health, and they should be informed of the reason for any survey that is made of potentially hazardous conditions. This precaution will alleviate their fears concerning possible effects on their health, will reduce speculation on why someone is checking their working conditions, will encourage them to cooperate in providing information, and will enlist their support and use of corrective measures.

While collecting data, the person making the survey should ascertain that normal conditions exist. Sufficient time should be spent on the job so that all conditions of exposure are considered, and all concerned should be satisfied that the problem has been thoroughly investigated and that all necessary information has been obtained. Frequently, workers and supervisors have been familiar with the hazardous condition for a long period and may have excellent suggestions on ways of correcting or overcoming it. Their suggestions and

advice should be sought and considered.

After all the data have been collected, the information should be assembled into a complete report. The report should include a statement of the problem, the procedure of investigating, the technique in the use of measuring devices, a compilation of the data, summary statement of the conditions found, and recommendations for correction. Before the final report is presented for consideration, it is advisable to review the results with the supervisors involved. This procedure will assure that the recommendations are practical and will enlist the supervisors' assistance and cooperation in correcting the hazards. Credit should be given for any specific suggestions used that were made by the workers or supervisors. Although reports of surveys are prepared in detail, when transmitted to management a brief summary should be included that covers the problem, conditions found, and recommendations made.

12. EDUCATIONAL ACTIVITIES FOR ACCIDENT CONTROL

12.1 EDUCATION DEFINED

Education for accident prevention is the systematic development and cultivation of natural powers by instruction, training, and example. The goal is accident-free production.

12.2 IMPORTANCE OF PSYCHOLOGICAL FACTORS

All accidents, whether directly caused by unsafe acts of workers or by the presence of hazardous conditions, may, if traced to their origin, be attributed to the faults of persons, either from the worker groups or the management. Psychological influences must be considered in the selection, placement, induction, and training of workmen. Accident-prone workers are those whose characteristics and behavior are such as to make them considerably more liable to injury than the average person. Recklessness, stubbornness, or excitability, low intelligence, lack of interest in the job, or dislike of the foreman, make these workers difficult to train and lead them to unsafe acts, many times deliberately.

Psychology is important in arousing and maintaining enthusiasm for safety through the usual media of meetings, posters, first aid training, and so forth. However, it is difficult to reach every worker through these means because messages must be addressed to whole groups of employees. Appeal cannot be made to each man's individual desires or traits but must be made to those most commonly felt by the largest number of employees. These will strike a responsive chord in some individuals but leave others untouched. Therefore, the supervisor is the key man in any induction and training program that considers psychological factors as they relate to safe performance. The foreman must apply practical psychology. He is in close contact with the employee and is in the best position to judge abilities and evaluate work performance, including safety factors. He must familiarize himself with the employee's likes and dislikes, his family situation, his financial troubles, and his background, which may influence his attitudes and on-the-job performance. If the foreman can adapt his training methods to appeal to the worker's individual desires and traits, there is a good chance that the worker will perform his job in a safe manner. It is important that consideration of the psychological factors be continued not only during the training period of an employee, but also throughout his employment.

12.3 INSTRUCTION STARTS WITH EMPLOYMENT

Normally, instruction starts when an employee reports for work. Most phases of his work should be gone over with him until he is fully apprised of every detail. Because habits (which

are perfectly learned performances) are developed through repetition, work methods should be constantly observed and improper methods should be immediately corrected. Instruction implies a personal relationship between the supervisor and the employees as individuals. Since this relationship is established from the beginning of employment, the supervisor is the prime factor in its success or failure.

Whenever work methods are to be changed, employees should be prepared in advance, and adequate instructions should be given to assure a smooth transition from the old way to the new. Merely assuming that workers will get the hang of the change is inviting trouble.

12.4 COMMITTEES AND MEETINGS

A safety committee is organized in a great many plants. Its membership should contain the supervisors and one or more representatives from each division. They may be lead men or line workers. Membership should be small enough to be workable and should be rotated to give experience to the largest number possible. Objectives for the committee ought to be set before it is organized, and only those ideas should be entertained that work toward such objectives. A secretary is needed to record proceedings. When there is no longer a need for a committee, or when interest wanes, it should be dissolved.

A plant always needs good safety meetings to bolster its over-all program. To maintain a level of interest, they must appeal to the employees and should be well prepared. An agenda along the line of the following may be of assistance:

1. Start meeting on time.
2. Opening remarks—brief.
3. Review status of safety suggestions.
4. Collect new safety suggestions.
5. Very brief discussion of accident statistics.
6. Introduce main feature of the meeting.
7. Request comments from visitors.
8. Express thanks to participants and those attending.
9. Close meeting on time.

Sources of material for program features are numerous. Whatever is selected should have a definite application to problems. Some of the following may stimulate other good ideas.

1. A safety subject dealing with some phases of accident experience that is giving trouble locally.
2. A talk by some outside expert—e.g., a doctor or an equipment expert.
3. A motion picture or slide film pertinent to the situation.
4. Statistical reports.
5. Articles or professional papers from trade journals, accident-prevention bulletins from such agencies as U. S. Bureau of Mines and National Fire Protection Association.

12.5 PUBLICATIONS AND VISUAL AIDS

Periodicals such as safety magazines (house publications) are a good method of getting messages across. Great care should be taken that the editorial content is readable. It should appeal to the intellectual level of those to whom it is directed.

Special bulletins, with adequate illustrations, may be put out to cover procedures in combating hazards. Where more detailed information is required, a manual may be issued—e.g., for investigating procedures in industrial injury cases, automotive accidents, designing for safety, and so forth.

Motion pictures and other visual aids are of great value in training programs. Care should be exercised to preview content. Visual aids that are poorly edited, inappropriate, lack continuity, or show improper work practices can do more harm than good. Indexes of safety motion picture films and slide films may be procured from business and industrial photography magazines.

12.6 FIRST-AID COURSES

Since first aid has an off-the-job as well as on-the-job application, it offers an opportunity to sell employees on management's interest in their welfare at all times. Industrial associations, U. S. Bureau of Mines, and American Red Cross offer good courses. Many successful safety programs have been launched through courses in first aid for all employees. Men are thus informed that the company has or is starting a formal program.

12.7 CONFERENCES

Periodic seminars or directed conferences for supervisory personnel should be a cornerstone in the safety-training program. Since the supervisor is responsible for the efficiency of his segment of production, such training is essential to help him do his job. Production must be safe to be efficient. Such courses should embrace employee working relationships, industrial psychology, and allied information. Material for such meetings is available from many corporations and universities.

Since most states require a number of forms in the event of an industrial injury, forum meetings on administration of workmen's compensation are valuable. Information exchanged in these sessions enables supervisory personnel to understand the need for prompt, accurate reporting. Good reports facilitate administration and help in the preparation of valid statistical analyses.

12.8 MOTOR-VEHICLE DRIVER-TRAINING

Where fleet operation is part of a business, motor-vehicle accident prevention presents a problem. Driver-training activity, coupled with eye examinations, can help management control this situation. A meeting or a series of meetings can be arranged to present the basic causes for accidents and an explanation of the physical, physiological, and psychological forces that culminate in accident-producing situations. Stress should be placed on the need for individual responsibility in adjusting to traffic situations and in avoiding accidents.

12.9 MANAGEMENT ATTITUDE AND EXAMPLE

Instruction and training will be of little value without the third component—example. The employees will be influenced by the example set for them, since the supervisor represents management and management's thinking. If he supports a safety-education program because he has to, or if he gives it only lip service, he will get the same sort of response from his people. But enthusiasm for making safety a vital part of the everyday work activity will lead to a reduction of injuries in each phase of operation.

13. STATISTICAL REPORTS

Statistical reports are essential as a source of periodic information on progress or retrogression. They can quickly and effectively pinpoint weak areas where more effort needs to be expended on accident control. Such reports may be compiled for establishing:

1. Industrial injury frequency rates (disabling injuries per 1,000,000 man-hours worked).
2. Industrial injury severity rates (days lost per 1,000 man-hours worked).
3. Analyses of basic causes, nature of work, and types of accidents.
4. Motor-vehicle accident frequency rates (recordable accidents per 100,000 miles traveled).
5. Costs.
6. Any other pertinent subject, such as vision-testing results and pre-employment testing.

Such reports may be compiled monthly, quarterly, semiannually, or

ABC MANUFACTURING COMPANY Disabling Industrial Injuries - year 1952									
	Number of Disabling Injuries			Frequency Rate (Injuries per Million Hrs. Worked)			Severity Rate (Days lost per Thousand Hrs. Worked)		
Department	This Year	Last Year	Avg. Prev. 5 Years	This Year	Last Year	Avg. Prev. 5 Years	This Year	Last Year	Avg. Prev. 5 Years
Production	4*	3	4	4.1	2.9	11.2	6.25	0.30	3.22
Assembling	2	9	6	3.5	14.5	10.4	0.27	0.18	0.59
Warehousing	37	29	36	19.9	14.5	26.2	0.46	0.22	1.10
Maintenance	7	8	9	5.3	6.9	16.2	0.11	0.21	0.44
TOTAL	50	39	55	8.5	9.7	16.0	1.77	0.23	1.34

*Each asterisk indicates a fatality

FIG. **11.14** TYPICAL LAYOUT FOR STATISTICAL REPORT.

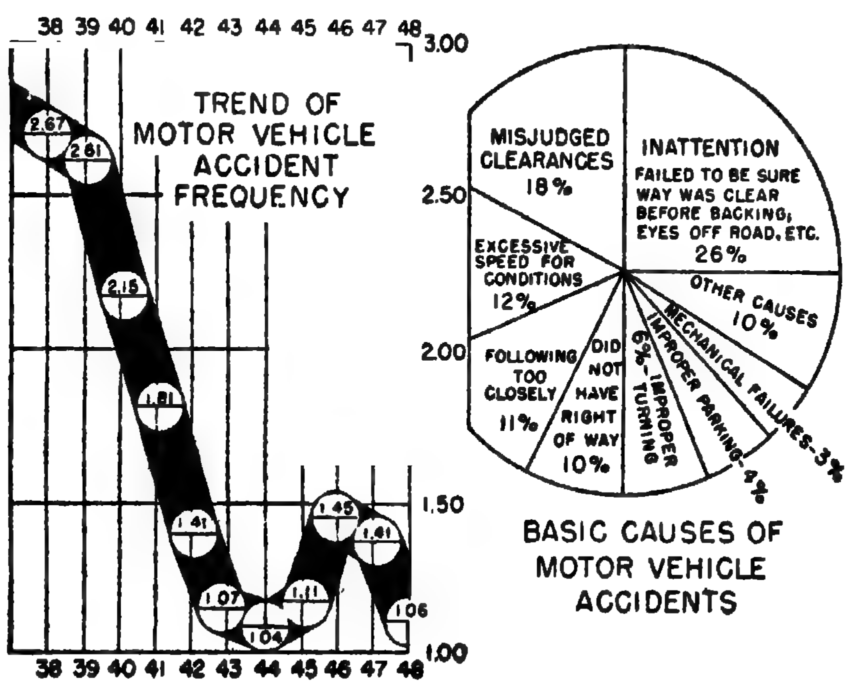
annually. Once the report system is in operation, it provides a means of comparing any given period with another—e.g., last year vs. a base period, say the previous five-year or ten-year averages.

The information should be concise and easily understood. Voluminous statistics are boring and often confusing. Consideration must be given to those who will read the reports.

A simple layout such as that in Fig. 11.14 may be used for the most frequently issued reports. Figure 11.15 shows an effective combination of a graph and a pie chart. The form of chart should be varied to keep them from becoming stereotyped.

Properly prepared, these reports may rapidly and graphically tell management in what direction the organization is headed accident-wise. They provide an educational tool for use in the safety program. They should be easily interpreted and be as brief as possible.

FIG. **11.15** FREQUENCY POLYGON AND PIE CHART.



Oliver E. Byrd, Professor of Education and Director of the Department of Hygiene at Stanford University, is one of the leading men in hygiene and health education in this country. He received the A.B., M.A., and Ed.D. degrees from Stanford University, specializing in Hygiene and Physical Education. He taught several years in public schools and junior colleges before joining the faculty of Stanford University. He earned his M.D. degree from the University of California School of Medicine.

Dr. Byrd is the author of twelve volumes of the *Health Yearbook*, published annually by the Stanford University Press. He also has written *Textbook of College Hygiene*, *Health Attitude Scale*, *Personal Health Inventory*, *Patient's Self-History Form*, and *Workbook for Health* and is one of the co-authors of *Education in War and After*. He has written numerous articles for professional journals.

He has been consultant in School Health to various counties and cities, consultant on military hygiene curriculum for the Air University, U. S. Air Force, consultant and Nutrition Workshop Director for General Mills Corporation, Utah State Agricultural College, Los Angeles City School System, University of Omaha, and Colorado State College of Education. He is also Chairman of the Western Advisory Committee, Paul S. Amidon and Associates, Consultants to industry on Educational Matters.

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SECTION 12

Industrial Hygiene

Oliver E. Byrd

1. INTRODUCTION

There are six basic facts regarding the health of the worker that should be well understood by management, labor, government, and any others who are concerned with the development of an industrial-health program. These are:

1. *The quality of the work performance of any employee is intimately related to his physical and mental health.*

This fact has been clearly established by the experience of industry and by scientific research. Anything that industry can do to raise its workers' level of vitality is likely to render concrete results in terms of reduction in absenteeism, increase in work output, diminution of labor turnover, and better worker morale.

2. *Management and labor are both affected by health conditions that prevail in an industry or in the community in which an industry exists.* This fact rests upon biological law. Health programs in industry should not be thought of as welfare efforts to improve the living standards of minor employees. The mental illness, for example, of even one high-ranking executive may have profound effects upon hundreds or thousands of other employees. The loss, for health reasons, of even one research worker, engineer, or other valuable employee may make the difference between success or failure in meeting the competition of other industrial organizations, if the significance of that employee is sufficiently great.

3. *Each kind of work has its special health hazards.* This fact is of primary concern to management and labor from the legal viewpoint. In every line of industrial effort, special studies should be made to ascertain whether or not a given kind of employment is healthful or hazardous so far as the worker is concerned. The great variety of jobs in industry makes it almost impossible to generalize on the nature of work hazards. Only analysis of each type of work can reveal the factors that reduce the efficiency of the employee or that produce serious impairment of his health. Reductions in the frequency of lawsuits and in the costs of industrial compensation can make the elimination of health hazards a profitable undertaking for management.

4. *Most worker illnesses are caused by factors totally unrelated to the occupation of the employee.* This fact is of great significance. The most effective industrial-hygiene program will be the one that is aimed at reduction of off-the-job sickness. This calls for a different type of effort than what is generally conceived as the industrial-health program and places a high premium upon health education of the worker.

5. *A sound industrial-health program can more than pay for itself when it is based upon real need, is carefully conceived, and is properly administered.* This fact is of practical importance. Unless labor, management, and government look upon the industrial-health program as a profitable undertaking for all, there is likely to be some limitation on the development of this phase of industrial relations. *No one stands to lose in a properly conducted program of industrial hygiene.*

6. *The industrial-health program is a public-health responsibility of the community as well as of labor and management.* In the development of any industrial-health program full cooperation should be given to public-health and other community health agencies for improvement of health conditions under which the worker lives. Family and community health factors are more important in most cases in establishing the health status of the worker than the conditions that exist on the job.

2. ATTITUDES OF GROUPS INTERESTED IN INDUSTRIAL HEALTH

2.1 THE ATTITUDE OF LABOR

2.1.1 Toward removal of health hazards. Organized labor in the United States has consistently fought for the removal of health hazards from industry. These efforts have been influential in protecting the health of the worker while he is on the job. Recently, labor groups have begun to take a more direct responsibility for the health of their members through the provision of union health plans for medical care of the worker and his family. All indications are that this aspect of industrial hygiene will undergo considerable development in the years ahead.

2.1.2 Toward industrial medical ex-

aminations. Occasionally, labor has reflected an attitude against certain health measures, such as the industrial medical examination. The basis for this objection has been that the examination was used for rejecting the work candidate, rather than for placing him properly after employment, or for discharging an employee found to be suffering from some disabling condition. Proper use of the examination, for the protection and the job placement of the worker, rather than for rejection or discharge, has tended to dispel labor's objection to this phase of the industrial medical program.

2.1.3 Activities of labor groups. In the main, labor groups have shown a wholesome and desirable concern about the worker's health, as is illustrated in the following typical activities:

1. Protective legislation. Labor unions have been very effective in securing passage of laws for the removal of health hazards and in securing mandatory compensation for death or illness from industrial accidents and disease.

2. Protective contracts. Union agreements with employers have been broadened to include provisions that insure healthful working conditions and, in some instances, health and disability benefits.

3. Health services to union members. Organized labor has been steadily enlarging its efforts to provide health protection to its members through various activities, such as the following:

Life insurance.
Sickness benefits.
Direct medical care.
Direct dental care.

4. Health research. Some labor groups have established research agencies that have given attention to several kinds of health problems. An increase in research activities pertaining to health of the worker appears to be justifiable. Especially desirable is research that analyzes the health effects of various kinds of work and work environments.

5. Health education of members. Very few labor unions have attempted any extensive program of prevention of illness through education in the causes of sickness. A few labor groups, however, have pioneered along these lines.

6. Support of health programs for the general population. Both the A.F. of L. and the C.I.O., as well as other labor organizations, have strongly endorsed a national health program.

2.2 THE ATTITUDE OF MANAGEMENT

Management has come to have a broader viewpoint on the protection and improvement of the health of employees. Early efforts were largely confined to providing a safe environment for the worker and to rendering medical aid in case of injury. Today, some of the most farsighted plans for the health supervision of workers have been initiated by enlightened management, rather than by labor or government.

1. Compliance with mandatory legislation. In general, management readily conforms to legislation aimed at protecting the health of the worker.

2. Increasing recognition of moral responsibilities. Programs to reduce occupational accidents and disease, the employment of handicapped workers, the re-employment of persons compelled to leave work because of illness, and other practices indicate that with many employers humanitarianism is a prominent reason for protecting the health of their workers.

3. Voluntary removal of health hazards. Management has shown an increasing desire to improve the working environment even when not compelled by law to do so.

4. Health research. Industrial research has not been concerned primarily with health, but there are some noteworthy examples where management has contributed to the improvement of worker health through fundamental investigations.

5. Recognition of financial advantages. Industrial leaders have seen the wisdom of improving worker efficiency in order to lower the costs of produc-

tion. Although financial results sometimes are not too obvious, there is good evidence that health programs more than pay for themselves.

2.3 THE ATTITUDE OF GOVERNMENT

Federal, state, and local governments have accepted the responsibility of occupational hygiene in a belated but wholehearted manner. Industrial-hygiene programs are now accepted as an integral and indispensable part of every public-health organization. A real effort is being made to bring public health to the general population through expansion of industrial-health programs.

Federal agencies. Contributions to worker health have come from a number of different federal agencies, but the following have made special efforts to serve industry:

1. Federal Security Agency, U. S. Public Health Service, Division of Industrial Hygiene.
2. U. S. Bureau of Mines.
3. U. S. Department of Labor.

State agencies. Prior to 1936, there were only three or four state departments of health that had separate administrative units dealing with industrial hygiene, but since the passage of the Social Security Act a great number of states have organized Divisions of Industrial Hygiene. The exact title, function, and location of these units in the governmental structure vary in the individual states.

2.3.1 Governmental activities. Governmental activities in the field of occupational hygiene are much more extensive than is generally realized. There is every indication that an intensification of service in this field is to be expected.

Legislation. One of the most obvious indications of governmental attitude toward the health of the worker is the actual legislation designed to protect the employee. Such legislation includes:

Compensation laws.
Safety laws.
Vocational rehabilitation.
Social Security Act.

Financial support. In recent years, large amounts of federal money have been made available for expansion of industrial-hygiene programs.

Research. Much valuable research relating to industrial health has been carried on in government laboratories. Until recently, such research was confined largely to federal agencies and a few universities.

Survey service. One of the most valuable aspects of governmental activity in the field of occupational hygiene has been that of cooperation with management or labor in making surveys of health conditions in different industries.

Educational services. Some extensive educational programs in occupational hygiene have been attempted by governmental agencies. This service will probably expand in the future.

Advisory and consultative services. Both federal and state agencies have served as sources of expert opinion and guidance in the field of occupational hygiene.

2.4 ATTITUDE OF OTHER AGENCIES

Certain voluntary and professional, as well as commercial, organizations have made valuable contributions to the problems of occupational hygiene. Such agencies have demonstrated real leadership in this field and have carried on research and other activities that have often paved the way for advances that could not have been made otherwise.

Two of the organizations that are especially prominent in providing voluntary or professional leadership are the American Public Health Association, through its Section on Industrial Hygiene, which was organized in 1914, and the American Medical Association, with its Council on Industrial Health.

Many other local organizations provide specialized services for labor or management in the field of health, and full exploration of these local resources should be made.

The American Social Hygiene Association, for example, has worked actively with industrial groups in the control of venereal disease and in health education of the employee group on this problem. The National Tuberculosis Association has rendered valuable services in detecting tuberculosis in working groups and in educating employees on the subject of tuberculosis. The American Cancer Society has contributed funds for research in industrial cancer and has supplied health-education materials for use by workers and by the general population. A great many other voluntary health organizations have likewise worked with industrial groups in promoting health.

3. ABSENTEEISM IN INDUSTRY

3.1 COST

When a worker is absent from his job, he is likely to undergo a personal financial loss, and industry is likely to suffer in terms of efficiency and production. Society inherits both losses. Absenteeism, especially that due to illness, profits no one.

The exact cost of worker absences is difficult to compute because it is bound up with the kind of work involved and with the experience, skill, and ingenuity of the employee. One report from 58 utility companies indicates an average cost to the companies per year of $56 per employee for absenteeism.* Obviously, this figure cannot be applied to all industries because of different circumstances, but it does illustrate the general principle that when a worker is absent from his job it costs his company money.

3.2 RATES

Absenteeism rates during World War II in different war industries varied from about 4 to 15 per cent, with a common rate of about 6 to 8 per cent. Substantial reductions in worker absences were achieved when special attention was given to worker health, especially when a planned approach to the problem was made through cooperative efforts of management and labor.

Although numerous studies have been made on this problem, it is difficult to be certain just what is the irreducible minimum in terms of worker absences caused by illness and injury. It appears that *any absenteeism rate over 3 per cent can probably be reduced by special attention to the problem.*

In general, sickness rates and absenteeism are greater among female employees. Hence, organizations that employ large numbers of women need to pay particular attention to this problem. Figures compiled by the United States Public Health Service over a period of 10 years show that disabling illnesses lasting over 8 days or longer are about twice as frequent among women workers as among male employees.* Data on this subject for the years from 1941 to 1950 inclusive are given in Table 12.1. Figures are rounded to the nearest whole number.

TABLE 12.1

Year	Average annual number of absences lasting 8 days or more per 1,000 workers: Males	Females
1941	101	163
1942	106	163
1943	138	204
1944	141	221
1945	147	258
1946	115	248
1947	112	260
1948	105	257
1949	96	255
1950	117	258

* "Have You Heard What Absenteeism Costs?" *Occupational Health,* Vol 12, No. 8, August 1952, 135.

* Division of Occupational Health, United States Public Health Service, "Frequency of 8-Day or Longer Disabilities, 1941-50." *Industrial Health,* Vol. 11, No. 12, December 1951, 184.

3.3 CAUSES

Sickness absenteeism in industry is a reflection of many different factors. It varies according to age, sex, lack of job satisfaction, nutrition, housing, general sanitation in the community, and many other factors. Regardless of the origins of worker illness, however, two conclusions can be drawn from the experience of industry with this problem: (1) Absence from work results in a financial loss to both the employee and his employer. (2) Sickness absenteeism can be reduced to a certain minimum with profit to all concerned.

Public-health and industrial statistics show that most worker absences are caused by illness and injury sustained *away from the job*. Industrial management's preoccupation with accidents incurred while the employee is at work has brought lower compensation insurance rates and has been profitable for both labor and management. But the greater possibilities of profit to both from reduction of off-the-job injuries, which occur twice as frequently, *have been virtually unexplored*.

Of even greater significance is the possibility of reducing worker absences by giving serious attention to ways of reducing illness rather than to ways of reducing accidents. For every one absence lasting eight days or more caused by nonindustrial accidents, about nine are caused by sickness from causes other than accidental injury. The development of health-education programs in industry aimed at off-the-job causes of illness has scarcely begun, but it is probable that only through this type of activity can much progress be made against these factors.

Records on causes of worker absences are likely to be incomplete and to have restricted meaning unless they are compiled for a particular group of workers. Some understanding of the causes of sickness absenteeism can be obtained, however, from analysis of existing reports on industry in general. The United States Public Health Service has reported each year on industrial absences

TABLE 12.2 INDUSTRIAL ABSENCES CAUSED BY ILLNESS 1941-1950

Rank	Cause of absence	Annual number of absences lasting 8 days or more per 1,000 workers	
		Male	Female
1.	Influenza and grippe	17	32
2.	Off-the-job accidents	12	16
3.	Bronchitis	7	11
4.	"Stomach disorders"	6	3
5.	Pneumonia	5	4
6.	Sore throat and tonsilitis	5	16
7.	Rheumatism	5	4
8.	Heart disease	4	2
9.	Appendicitis	4	12
10.	Skin diseases	3	5
11.	Diseases of the genito-urinary system	3	19
12.	Neuralgia and neuritis	3	3
13.	High blood pressure	2	1
14.	Hernia	2	1
15.	Neurasthenia	2	11
16.	Diarrhea and inflammation of the intestines	2	6
17.	Tuberculosis	1	1
18.	Cancer	1	1

TABLE 12.3* TEN MOST COMMON HEALTH PROBLEMS OF EXECUTIVES

Rank	Disease	Number
1.	Obesity (Overweight)	127
2.	High blood pressure	60
3.	Pyorrhea	55
4.	Hemorrhoids (piles)	50
5.	Hypothyroidism (low basal metabolism)	39
6.	Hernia	37
7.	Sinus disease	34
8.	Psychoneurosis	33
9.	Arthritis	33
10.	Duodenal ulcer	24

* Earl F. Lutz, "Health Examinations of Industrial Executives," *Industrial Medicine*, Vol. 17, No. 2, February 1948, 65-69.

caused by illness since 1920. Table 12.2 represents a rearrangement of data from this source for the ten-year period from 1941-1950 inclusive.* Absences caused by industrial accidents and venereal diseases are not included, nor are absences of shorter duration than eight days. Statistics of this sort give only a partial picture of the causes of sickness absenteeism. Figures in the table have been rounded to the nearest whole number in addition to being rearranged, and only major specific illnesses are included.

Certain illnesses or deaths are caused by factors directly related to the job. The nature of these hazards can be determined only by analyzing the specific work involved. The great variety of jobs makes it almost impossible to predict job hazards without such an analysis. *Every kind of work has its special health hazards.* If the worker's health is to be safeguarded, health hazards both on the job and off the job must be considered.

The health problems of certain work groups may be significantly different from those of others. A General Motors Corporation study of the health of 718 executives revealed the ten most commonly encountered health problems. These are listed in Table 12.3.

* W. M. Gafafer, "Industrial Sickness Absenteeism among Males and Females During 1950," *Public Health Reports*, Vol. 66, No. 47, November 23, 1951, 1550-1552.

3.4 RECORDS

Important information on the causes of absenteeism can be obtained on a systematic basis only if records are kept. Sickness records, however, often are not sufficiently analyzed or else are not kept in such a manner as to make adequate interpretation possible. The following suggestions for keeping absenteeism records have been made by experienced industrial hygienists:

1. *Records should be kept of every worker absence of one day's duration or more*, providing these data are used for an analysis of the causes of absenteeism. Obviously, there is little sense in keeping records unless they are to by systematically interpreted.

2. *Absence records should be carefully compared* by different departments, plants, supervisors, and so on, in order to locate areas of operation in which there are special hazards to the workers' physical or mental health.

3. *Absenteeism records should be compared with those of other industrial organizations* so that data can be interpreted on a broad industrial basis as well as on a more specific interdepartmental basis. It is not always possible, of course, to obtain sickness data from other industrial organizations.

4. *The absence records of individual workers should be used as a basis for*

counseling, medical service, and other guidance activities in personnel problems. The use of the individual worker's records for this purpose is particularly advisable in advancing health education.

5. *Absence records from male and female employees should be kept and studied separately* because of differences that might otherwise be obscured by the total absenteeism rates. Industrial experience in general has shown that there may be marked differences in both the absenteeism rate and the cause of absenteeism between the two sexes.

4. INDUSTRIAL FATIGUE

Fatigue of whatever origin lowers or destroys working efficiency. Compensation in the form of rest is necessary at periodic intervals even for the healthy worker. Although it is normal for a worker to become tired when he expends effort, it is not normal for him to remain tired. The speed with which he recovers from fatigue is thus an important indication of his need for rest or for correction of some fundamental cause.

4.1 CAUSES

When fatigue does not yield promptly to rest, it is important to look for some basic cause other than the work activity itself. Fatigue may be caused by the personal health habits of the worker, such as insufficient sleep, undernourishment, and excessive activities after work. Fatigue on the job may be caused by worry and anxiety about off-the-job factors, such as family problems. Poor body posture, flat feet, chronic disease, and many other factors may cause fatigue. Communicable disease, such as tuberculosis, may give a long-lasting, persistent fatigue. Some factors on the job, such as noise and poor ventilation, may be involved. Defective vision may cause fatigue on jobs that require finely detailed work.

4.2 PROGRAM FOR REDUCING FATIGUE

A program to relieve industrial fatigue should not be restricted solely to an evaluation of the worker's environment or of his work habits on the job. When a large group of workers exhibits fatigue, it is well to suspect some factor in the work environment, such as excessive noise, harmful vapors, poor emotional relationships between the workers themselves or between the employees and management, or any one of a number of factors that may be revealed only by careful analysis of the work situation. However, when an isolated worker shows excessive fatigue, a personal problem is usually responsible. In this case, it is well to start with a medical examination for the individual worker. The possibility of disease should always be explored in both individual and mass complaints of fatigue. A periodic physical examination for all workers provides an important means of evaluating the physical status of the worker in relationship to fatigue. When illness is found to be the cause of fatigue, corrective efforts must be based upon medical treatment of the basic cause.

The following factors may be useful in reducing worker fatigue:

1. Medical examination of all workers at periodic intervals. Special examinations for individual workers in whom fatigue is especially apparent.

2. Multiple feedings. Mid-morning and mid-afternoon snacks help to reduce fatigue and frequently contribute to greater worker efficiency. Care should be taken, however, to see that the between-meal feedings are well administered so that there is not an excessive loss of time from the job. Such a loss might counteract the advantages secured through improved efficiency.

3. Alternation of work and rest. Each specific kind of work has its maximum work-rest ratio in terms of efficiency and output. Only careful scientific study can ascertain the particular ratio that is best on a given job. The cooperation of both employees and management

should be sought in determining this proper ratio.

4. Health vacations. Many vacations destroy or impair health rather than improve it. One of the functions of a personnel department might be to assist the worker in planning a health vacation, in conjunction with advice from the medical officer.

5. Reduction of noise. Many studies have demonstrated that even in office work the control of noise improves work efficiency.

6. Protection of vision. Poor illumination and glare may be a major source of worker fatigue on certain types of jobs. Since good vision is basic to almost all work, special pains should be taken to see that the worker is protected.

7. Proper environmental work conditions. Temperature, humidity, and ventilation have a great deal to do with comfort and, therefore, with efficiency on the job.

8. Emotional relationships among workers. Worry is a prominent cause of fatigue in many employees. The worry may be associated with dissatisfaction on the job or with problems at home. Regardless of its origin, the worker can be made a more efficient employee if his problem is resolved through assistance from the medical officer or the personnel department.

9. Relaxation. Workers can be taught how to relax physically with profit to themselves and to industry. This is a matter of direct demonstration and education. It often pays good dividends in improved efficiency.

10. Grouping of worker by similarity of temperament. This factor has been shown to produce more efficiency on the job.

11. Health education. A sustained program of health education may convince workers of the value of good nutrition, proper sleep, and other factors related to health and efficiency.

5. BODY MECHANICS

The significance of body mechanics or posture in relationship to work efficiency is often overlooked by industrial management and labor alike.

One study of school children which involved the use of the Iowa posture test and medical examinations has shown that there is a significant association between poor posture and certain physical and emotional factors such as disease, fatigue, self-consciousness, hearing defects, timidity, underweight, heart disorders, and asthma.

Poor body mechanics on the part of the industrial worker has two significant aspects. First, the defective posture may be due to illness, fatigue, or various other factors that may or may not be associated with the work involved. Second, the poor posture may be a direct cause of fatigue and impaired efficiency on the job. Thus, it is imperative to approach the problem of posture in industry from the standpoint of both cause and effect.

In some instances, work output has been measurably increased by training workers in proper body mechanics in relationship to the work being done. Also, good posture may be important in reducing injuries to workers. For example, workers who are trained to lift properly have fewer back and other types of injuries than those who have never learned to lift heavy weights properly.

Any attention given by industrial groups to the problem of posture should be based upon the fundamental concept that good posture is proper body mechanics in action on the job. The following suggestions should be helpful in improving the body mechanics of the worker in relationship to his work:

1. The periodic examination of the worker should contain *an appraisal of his posture.*

2. *Workers should be studied* in relationship to body mechanics *while they are on the job.*

3. *Instruction* should be given in proper body mechanics, especially in the lifting of weights.

4. *The work environment should be carefully appraised* in respect to its influence upon the posture of the worker.

The height of the work table, for example, may be an important cause of poor posture.

5. Employees should be *encouraged to use stools, chairs, or any other devices that reduce body fatigue.*

6. THE HANDICAPPED WORKER

The problem of the handicapped worker is a major one in the United States and constitutes a challenge toward which every industrial organization should establish a policy of action. In recent years, both industry and society have accepted this challenge. In the 12-year period from 1940 to 1952 nearly 2½ million handicapped workers were placed in industrial jobs, and hundreds of thousands of others found work in agricultural service.

The cooperation of industry with government and other agencies in finding work for handicapped workers is not based solely on altruism. Studies have shown that the handicapped employee is often a more dependable worker than the worker without physical defects. In other words, employment of the physically handicapped worker is good business for both industry and for the nation.

Numerous problems confront industry when handicapped workers are employed, but these may be overcome when compensation boards make sound appraisals of the degree of disability present at the time of employment, when labor organizations do not insist that all new employees start with the more arduous tasks, when state legislation pertaining to second injuries of the handicapped worker is sensible and considerate of both employee and employer, and when industrial or other physicians make a careful and accurate appraisal of the disabled worker's handicaps and abilities.

The following principles may serve as a guide to management and labor in regard to the employment of handicapped workers:

1. A certain percentage of new workers should be employed from the ranks of the handicapped as a standard, annual procedure.

2. Pre-employment medical examinations should be used for matching abilities of the handicapped worker to job requirements, rather than for rejection of the work applicant.

3. The pre-employment medical examination of handicapped workers should establish as accurately as possible the degree of disability present at the time the worker is hired. This is to safeguard industry from unjust compensation awards in case of second injuries.

4. Labor and management should cooperate with rehabilitation agencies in the community, state, or region for better preparation, treatment, and placement of disabled workers. This includes notifying rehabilitation agencies of men or women who need assistance.

5. Direct rehabilitation of employees in need of such attention because of injury or illness received while in the employ of the organization involved should be a regular part of the company's medical program. In some industries special job adjustments can be made that assist in rehabilitation while the employee is on the job.

6. Emphasis should be placed by management on residual capabilities rather than on disabilities in all associations with handicapped workers.

7. INDUSTRIAL COMPENSATION FOR ILLNESS

Compensation benefits for industrial accidents to workers have been well established in the United States. In recent years the right to compensation for disease due to occupation has also been recognized legally in various states.

A newer trend in state labor legislation has been the movement toward payment of benefits to workers who suffer unemployment because of illness unrelated to the work involved. In 1942, Rhode Island became the first state to provide non-work sickness insurance.

California became the second state to pass a sickness disability law in 1946, and since that date three additional states have provided such benefits. In 1952, 26 states, Alaska, the District of Columbia, and Hawaii provided full coverage for occupational diseases in their compensation laws. The general trend in compensation has been to increase benefits. In 1952, Pennsylvania became the 27th state to set benefits of 30 dollars a week for temporary total disability.

It is apparent, then, that industry must give attention to the prevention of worker illness due to both occupational disease and non-work illnesses if compensation costs are to be reduced to a minimum.

8. HEALTH EDUCATION IN INDUSTRY

The industrial-hygiene program should be directed primarily at the prevention of illness among workers rather than at the detection and treatment of disease. Education of employees on health matters is the most important and most essential factor in any program of prevention.

To achieve effective and continuing health education, industry should cooperate with and support health-education programs in the schools and community and should carry on certain health-instruction efforts of its own.

There are many different ways of teaching. So far as the worker is concerned, these methods can be classified into two broad categories. The worker can learn by *taking part in the activity himself*, or he can learn by a more passive method of *listening to others, observing demonstrations, illustrations,* and so on. Of the two methods, the one that affords the worker the richer *experience* is the better, but passive forms of learning should not be neglected.

8.1 WORKER PARTICIPATION

Learning is most complete when the worker takes part in the organization, planning, execution, and evaluation of the health-instruction program. The following examples suggest how the worker can be sensitized to the health problems in his organization and how he can be stimulated to learn through his own activity:

1. Job analysis by the worker to discover health hazards.
2. Participation on worker committees to attack special health problems. Some examples are:
   Safety committee.
   Nutrition committee.
   Fatigue committee.
   Committee on communicable disease.
3. Individual study and research on health problems associated with the worker's job.
4. Preparation of health exhibits related to work and non-occupational factors.
5. Participation in health demonstrations.

8.2 TRADITIONAL TEACHING METHODS

Of the many teaching methods that have been used for thousands of years, some have special implications for industry. But all these methods should be investigated for possible use in a specific occupational-hygiene program. Some examples follow:

1. Individual instruction of workers in health practices through demonstration by trained supervisors, foremen, or older and more skilled workers. On-the-job instruction is most meaningful to the worker. Safety instruction is one of the best examples of this type of teaching.
2. Group instruction on the job by trained foremen, supervisors, or older and more skilled workmen. Same method as the above, but the instructor teaches a small group instead of an individual worker.
3. Individual consultation with the physician or other qualified person. This method can be very effective, since it gives the worker a chance to bring his personal health problems for analysis. The management needs to stimulate this

kind of instruction by making it convenient and desirable for the worker to ask for this expert advice.

4. Group health instruction through lectures, classes, discussion meetings, and so on.

5. Individual and group instruction through pamphlets, leaflets, and other printed materials.

6. Extension classes in hygiene, such as those carried on by mail.

8.3 USE OF COMMUNITY FACILITIES

In every community there are various organizations interested in the health of the general population, including that of the workers in industrial establishments. To overlook the resources and services of these official and voluntary health agencies is to deprive the company of both expert and, often, free assistance in the health-instruction program.

8.3.1 The schools. Programs of industrial-health education can often be arranged through the local schools. A request for the addition of an industrial-health course to the adult or evening-school curriculum may stimulate the schools to a greater interest in this field. When industry can indicate its educational needs in this field, the school officials are usually quite willing and even anxious to provide instruction to meet them. Industrial support for health-education programs in the elementary and high schools may provide the stimulus for development of a more adequate school health program in general.

8.3.2 Voluntary health agencies. One of the primary functions of the private or voluntary health agency is to educate the public on specific health problems. If the occupational organizations are willing to cooperate, they can have the expert assistance of qualified persons in special health fields, such as tuberculosis control and first-aid. Voluntary health agencies are numerous, and they constitute a great reservoir of teaching materials for health-instruction programs.

8.3.3 The public health department. The local or county public health officer is frequently an invaluable aid in giving information about the health conditions and health problems with which the worker is confronted as a member of the community. The health officer has available a wealth of printed materials that he is anxious to distribute to the citizens of his community. He can also serve as a leading resource in making industrial surveys and developing adequate sanitation.

9. THE HEALTHFUL WORK ENVIRONMENT

The physical environment is of particular significance to the health of the worker because of the great variety of hazards that may exist. These hazards may result from the use of toxic materials, dangerous processes, moving machinery, or other factors.

Each occupation has its own health hazards. To discover them, it is essential that an industrial-hygiene survey be conducted before the health programs are established.

Most industries have overlooked the fact that the health of the worker is influenced by his home and community environment as well as by conditions on the job. Sometimes these may be more important than the work conditions. Management must, therefore, support home and community sanitation in order to provide the best possible health for employees.

In any survey of the work environment or its health potentials, attention should be given to the following: (1) the water supply, (2) sewage disposal, (3) personal service rooms, (4) temperature and ventilation control, (5) sanitation, (6) illumination, (7) noise control, (8) the use of toxic materials, (9) building construction and maintenance, (10) housekeeping and storage, (11) the adequacy of tools and mechanical equipment, and many other factors dictated by the nature of the work involved.

In some instances, the use of technical equipment to measure air contamination is essential. Assistance from state bureaus of industrial hygiene may be valuable.

10. MENTAL HYGIENE FOR WORKERS

The mental hygiene of the worker has definite relationships to efficiency on the job. Both home and community as well as occupational environment should be considered in terms of psychological relationships. The general organization of the company in which the worker is employed should facilitate both personal and group adjustment. The cornerstone of this structure is for management to have *an interest in the worker as an individual person.*

10.1 PREVENTIVE PROGRAM

Occupational therapy is one of the approved means of *treating* mental illness. This should give some indication of how important occupational adjustment may be in *preventing* psychological maladjustments, especially in employees who are fundamentally stable.

10.1.1 Determination and promulgation of administrative policies. One of the first steps in preventing emotional maladjustments should be taken by the administrative officers. A simple and concise statement of the attitude and policies of the organization on matters that affect mental health should be drawn up and made known to both minor executives or work supervisors and the rank-and-file employees.

10.1.2 Selection and training of minor executives. Unless foremen, supervisors, department heads, and other minor executives are emotionally well adjusted and have an understanding of the principles of mental hygiene, they are likely to be a source of conflict and maladjustment on the part of the workers. In-service training of these company officers in human relationships may bring about great progress in industrial relations in a specific organization or industry.

10.1.3 Selecting and grouping employees according to emotional patterns. The worker's association with other employees is a very important source of adjustment or conflict. Employees should be grouped in accordance with the principles of group adjustment. Similarity of ideals, temperament, likes and dislikes, and so on, should be a factor in the placement of workers.

10.1.4 Adaptation of work to employee capacity. Efforts to place the employee on a job that he likes will be repaid by returns in adjustment and efficiency. This adaptation calls for an analysis of the worker and of the job. Only when *both* have been evaluated will adjustment between the two be likely.

10.1.5 Establishment of a mechanism for adjusting conflicts. In addition to the previous measures, some method or channel should be provided for workers to express themselves on disagreements or conflicts. This mechanism should provide a means of continuous self-analysis on the part of the management and will afford the worker satisfaction and relief in getting complaints off his mind.

10.1.6 Personal guidance program. A personal guidance program that offers constructive criticism, friendly suggestions, and a program for advancement leads to a greater feeling of adequacy and accomplishment among workers. The worker is inspired to a greater sense of security and confidence in both himself and his employer. Guidance need not be limited to problems that arise on the job. Frequently the source of the most distressing conflict is in the home or community.

10.1.7 Program of recreation. The provision of adequate recreational facilities and programs does much to satisfy certain workers. A carefully planned program that includes services to the worker's family, including adult as well

as youth activities, is most likely to accomplish its purpose.

10.2 DIAGNOSTIC PROGRAM

It is important that the worker with psychological difficulties be discovered and treated if he is to be retained on the job. The worker with poor mental hygiene is likely to have an unwholesome effect upon the emotional development of other workers unless the source of his difficulty is discovered and ameliorated.

10.2.1 Psychological testing. Psychological tests, properly used and interpreted, are of value in industry. If the testing is done by untrained personnel and if the limitations of the tests are not taken into account, however, too much reliance may be placed upon them.

10.2.2 Recognition of symptoms of maladjustment. Minor executives, departmental heads, foremen, and supervisors are the key persons in any program of detecting worker maladjustments. Although these persons are not adequately trained to make diagnoses, they can be taught to recognize symptoms that may demand expert attention.

10.2.3 The medical examination. This is the first exploration by technically trained personnel. Mental-hygiene difficulties often originate in the physical ill health of the worker. The presence or absence of good physical health should be established at the outset of the investigation of the employee's mental hygiene.

10.2.4 Personal consultation. Consultation with the worker or with his family may do much to reveal the source of the psychological difficulty. Although discussions should be conducted, if possible, by a person trained in the field of mental hygiene, an untrained listener who is sympathetic and understanding can often do a great deal to alleviate conflicts in the employee's mind.

10.2.5 The psychiatric examination. If possible, this examination should be made by a medical man trained in psychiatry. Sometimes several business organizations enter into a group purchase of psychiatric services on a full- or part-time basis.

10.3 CURATIVE PROGRAM

The worker who is mentally ill is in need of medical aid just as much as the worker who suffers from physical disease. It should be realized that many minor and some major mental illnesses can be cured. If the employee is a technically trained and valuable worker, it will be especially profitable to restore him to useful service. The broader results of such treatment, in terms of favorable effect upon the other working personnel, may be considerable. Treatment is a technical matter that should not be attempted by the novice.

10.4 HOME AND COMMUNITY RELATIONSHIPS

Many worker maladjustments are caused by conditions and problems in home or community relationships. Management should acquaint itself with conditions that the worker encounters when he is away from his job. Knowledge of community resources in mental hygiene may enable the employer to utilize these sources as means of settling difficulties of his own employees.

10.4.1 Public-health departments. These agencies are establishing mental-hygiene services in increasing numbers. Although most of these services are in the experimental stage, the trend is toward expanded efforts to improve the mental health of the general population.

10.4.2 Professional and voluntary agencies. Some professional and voluntary agencies can render real assistance to industry in establishing and carrying on a program of mental hygiene. Labor and management should acquaint themselves with such agencies.

11. THE INDUSTRIAL MEDICAL SERVICE

11.1 ORGANIZATION

The organization of the health department within the industrial concern varies according to specific conditions. No single administrative set-up is best in all cases.

11.2 PERSONNEL

The physician should have, in addition to his medical training, some advanced study in the field of public health. Public-health nurses are preferable because of their training in the preventive viewpoint. The services of physicians, nurses, dentists, oculists, psychiatrists, and other specialists may be secured on a part-time basis, but their qualifications should be as high as if they were to be employed full-time.

11.3 EQUIPMENT AND FACILITIES

The extent of equipment and facilities depends on the scope of the medical services rendered. Some larger organizations have fully equipped physicians' offices, clinics, hospitals, rest homes, laboratories, and so on. In smaller plants, it is not feasible to provide elaborate facilities. The American Medical Association has indicated that an acceptable dispensary can be equipped with supplies and necessary equipment at a very reasonable cost.

11.4 FUNCTIONS

The functions of the medical department are determined by its administrative organization and authority. If the medical director has a sufficiently broad preparation, he may be designated to carry on or supervise the total industrial-hygiene program. Often his training best qualifies him to render medical treatment as his primary contribution. Although functions vary, some of the more important contributions from the medical department are as follows:

11.4.1 Medical examinations. The attitude of labor and management toward the interpretation and use of medical findings is very important and will probably determine acceptance or rejection of this service in the occupational world.

The medical examination in industry should not be used primarily for rejecting a work applicant or for discharging an employee. The fundamental purpose of the examination is to insure proper job placement and to maintain and improve the worker's health to the mutual benefit of management and labor.

11.4.2 Daily health inspection. Foremen, supervisors, and department heads are key persons in the functioning of an industrial-health program. They must be trained by the medical department to observe the workmen under their supervision from the health aspect as well as from the aspect of worker production. Although they are not qualified to diagnose illness, they can make daily health inspections to detect symptoms that call for referring the worker to the nurse or physician in the medical department.

11.4.3 Medical treatment. The extent of medical service provided by the medical department will be determined by the practical limitations of policy, personnel, facilities, and so on. Standards and policies need to be established by executive officers in order that the medical department may understand the nature of medical treatment to be rendered. Individual organizations differ greatly in the extent of curative treatment accorded the employee. The following examples illustrate these differences:

1. Medical and surgical care following occupational accident or disease only.
2. Referal to the family physician of workers who need medical attention.
3. Medical and surgical treatment of

workers regardless of cause of injury or illness—whether occupational or not.

4. Full medical treatment for all workers and their families.

11.4.4 First aid. First aid is provided in many organizations that lack adequate personnel and facilities to render medical care. Where medical departments do exist, there should be a planned program for giving first aid in case of emergencies. It is a function of the medical department to train foremen, supervisors, and workers in techniques for rendering first aid whenever advisable.

11.4.5 Extension services. Sick employees should be visited in their homes, in the hospital, or elsewhere. If the policy of the organization is to provide medical care, the follow-up program of treatment becomes an important part of the services rendered by the medical department. Home visitation by the nurse or physician can become an important means of developing good will toward and confidence in the industrial hygiene program. In the case of continued absence of workers, there should be an investigation to discover if the cause is a medical one. Visiting nurse service or home medical care can be placed on an optional basis where these services are available on request by the worker.

11.4.6 Educational services. The nurse and the physician have important educational functions in the industrial hygiene program. These functions include:

1. Education of the worker-patient while treatment is being provided.
2. Training of key workers in the principles and methods of first aid.
3. Training of foremen and other supervisors in the techniques of the daily health inspection.
4. Special instruction on health problems through lectures, consultations, committee meetings, and so on.
5. Education of workers during medical examinations.
6. Preliminary educational efforts of the nurse prior to medical examination or treatment.
7. Education in personal and group hygiene through home visitation by the nurse.

11.4.7 Keeping of records. One of the important functions of the medical department is to maintain adequate personnel records and records of accidents and disease that impair the working efficiency of employees. These records should include:

1. Analyses of all accidents or diseases that afflict the employee.
2. A personal health record for each employee.
3. A record of conditions or causes that result in injury or disease.
4. Tabulation of the number of employees sent to the medical department by the foremen or supervisors who are making daily health inspections. This record should enable the physician to discover those supervisors who are not cooperating in the detection of employees who need medical attention.

11.4.8 Immunization services. One of the important means of protecting the individual worker and his fellow employees is by the full utilization of available immunization procedures. It may or may not be advisable to make immunization compulsory, but wherever the health of the worker can be protected by this means, he should be encouraged to use this service.

11.4.9 Other functions. The functions of the medical department are numerous and detailed. Some of the services other than those indicated on the preceding pages are as follows:

1. Special case-finding campaigns.
2. Provision of specialized health services as needed.
3. Arrangement for hospital service if this is not provided by the company.
4. Provision of group insurance for employees.
5. Providing contacts between employee and community health agencies that may be of assistance to the worker.
6. Other services.

12. INDUSTRIAL DENTISTRY

Industrial dentistry is a field of specialization that has not been widely developed. There are only about

160 dentists trained and experienced in this field who are providing service in industrial plants.

Any adequate program of industrial dentistry must be based upon the total health of the worker. This means that any factors related to dental decay or disease of the dental tissues must be considered, since worker absence caused by poor dental health represents a significant loss to industry, regardless of the origin of the disabling condition.

Industrial support of community fluoridation of water, proper diet, and health education in oral hygiene must accompany any industrial dental program.

Although most dental health programs to date have been concerned primarily with the provision of dental care on an emergency basis (such as the relief of toothache), the value of even this limited service has been demonstrated. Dr. James M. Dunning,* of the Harvard School of Dental Medicine, has reported that in one industrial plant the provision of emergency dental service had returned to work over 85 per cent of the employees seen at the industrial clinic. In this plant, an average time of only ten minutes was needed to secure relief for the worker. The saving of man-hours may be substantial, since approximately 2 per cent of all illness absenteeism is due directly to dental pain. Dr. Dunning has also reported that at the Hood Rubber Company, a plant dentist who was serving a working force of approximately 5,000 was able to save more than enough man-hours to cover his entire salary.

Farney has pointed out that studies of industrial populations in Tennessee reveal that absenteeism because of diseases of the teeth and supporting structure amounts to about 47 per 1,000 employees. The severity rate, or length of absence for each worker with dental disorders, in this study averaged slightly more than 4 days per absence. It should be obvious from such studies that industry can well afford to give serious attention to the possibility of providing dental service for industrial workers. In the development of an industrial dental program, the following points should be considered:

1. *Absenteeism records should be analyzed* to see if the industrial force, in terms of numbers and severity, has a sufficient problem in dental health to justify the employment of an industrial dentist.
2. Any industrial dental program *should be integrated or correlated with the community program* in that area.
3. There should be *regular dental examinations* of all workers.
4. *Dental care should be broad and comprehensive* and should not be restricted to the care of the teeth alone.
5. There should be *periodic cleansing of the teeth* by the industrial dentist or the dental hygienist.
6. *Appointments* or referrals of employees with specialized needs should be made for the workers.
7. *Follow-up examinations* should be made of all workers as needed.
8. *A continuous, comprehensive program of health education* in respect to dental health should be carried on.
9. Fluoridation of community water supplies, if needed and recommended by local public health authorities, should be supported by industrial groups.

13. VISUAL HEALTH IN INDUSTRY

Although it has been estimated that about 1,000 eye injuries occur each day in the United States among the working population, the problem is not limited to industrial safety. (See Section 11, Art. 8.3.) Many eyes are damaged by poor nutrition, disease, heredity, and other factors. Any approach to the problem of visual health in industry that is restricted to accident prevention overlooks the importance of visual efficiency in relationship to the

* James M. Dunning, "Absenteeism Caused by Dental Pain Can Be Prevented," *Occupational Health,* Vol. 12, No. 6, June 1952, 90.

amount and quality of work performed by the employee. In other words, good vision is directly related to the efficiency of the worker.

In some states, the Industrial Commissions have adopted very specific measures for eye protection of workers, and penalties are imposed on employers who fail to provide this protection.

Studies suggest that visual fatigue plays an important role in the working efficiency of large numbers of industrial workers and clerks. Visual efficiency is not related solely to health of the eye. The amount of illumination available at the work surface and the presence or absence of glare may have an important relationship to the amount of visual fatigue experienced by the worker. In one experimental study on visual fatigue, it was shown that within a period of two hours it was possible to equal or exceed the amount of fatigue produced at the end of the working day on the job. In this experimental research it was shown that work performance improved markedly from 2 foot-candles up to 50 foot-candles, but that the efficiency of the workers changed very little at higher levels of illumination. The amount of illumination needed, however, depends upon the amount of detail and other factors involved in the work concerned.

Griffey* has reported that in a large coal company it was found that 75 per cent of the officials and employees had defective vision. Following the correction of visual defects in this worker group, 90 per cent showed improvement in production and wastage was reduced by 37 per cent. In another organization of 11,000 men it was found that 58 per cent had defective vision, including 21 per cent whose vision was exceptionally bad. It should be obvious in such cases that the efficiency of the employee can be improved by correcting visual defects.

The major causes of eye accidents in industry are flying particles and chemical substances that reach the eye. Although exceedingly important from the standpoint of the health of the individual worker and from the viewpoint of compensation costs in industry, such accidents are not a major cause of blindness in the general population. Meek* has reported a study of blindness in New York state which showed that causes of loss of vision were unknown in approximately 46 per cent of the cases, whereas cataracts ranked second and accounted for 26 per cent of the total cases of blindness. General disease accounted for 15 per cent. In 12 per cent of the cases the blindness was due to some prenatal influence, and infectious diseases accounted for 8 per cent of the cases. In this study, accidental injuries accounted for only 4 per cent of the blindness encountered. Cancers were at fault in 1 per cent of the cases.

A broad program of industrial effort for conservation of vision should be based upon a number of different points. The following measures are of particular value in protecting the eyes of workers:

1. Periodic *eye examinations.*
2. Protection of vision by *a well-balanced diet.*
3. Provision of *adequate illumination* on the job.
4. Use of *eye-protective devices* in industry,
5. An *educational program* to emphasize the causes of eye injuries and diseases.

14. NOISE AND THE CONSERVATION OF HEARING

Noise is an important problem in industry from several viewpoints. First, it has been shown that noise tends to decrease the working efficiency of the average person. Second, noise may be an important factor in the loss of hearing. Third, speech communication among

* Edward W. Griffey, "Sight Conservation in Industry," *Southern Medical Journal,* Vol. 43, No. 11, November 1950, 940-944.

* Raymond E. Meek, "The Causes of Blindness in New York State in the Years 1946, 1947, and 1948," *New York State Journal of Medicine,* Vol. 50, No. 20, October 15, 1950, 2433-2437.

workers becomes more difficult in the presence of noise. Fourth, the mental health of the worker to his family, his employer, and to society in general may be seriously impaired by reduction in hearing acuity.

No precise standards for the prevention of injury to the worker from noise have yet been established, although most experts agree that hearing may be damaged by persistent exposure to noise at a level of 75 to 100 decibels.

A study by Nash* has revealed that 730 workers in a concern making steel freight cars had experienced industrial deafness sufficient to entitle them to compensation claims. The noise level in this plant was found to be approximately 115 to 120 decibels. About 90 per cent of the men had worked in this atmosphere of noise from 10 to 30 years. All the injured workers were found to have a nerve deafness in both ears. This study, among others, has indicated quite clearly that it is a medical fact that the hearing of workers can be impaired by noise. The study also makes clear that the courts have upheld the right of such injured workers to receive compensation benefits for loss of hearing.

Noisy industries must install hearing conservation programs in order to protect the health of their workers and to escape from excessively heavy compensation liabilities.

Most hearing loss, however, does not come from industrial noise. By far the greatest cause of deafness in adult life is neglected ear infection in childhood. It has been shown that approximately 50 per cent of deafness in adults could have been prevented by proper medical care of relatively minor throat and ear infections in childhood. Other factors may also be involved in the loss of hearing, such as poor heredity, nutritional deficiencies, mechanical accidents, and blocking of the ear canal.

An adequate hearing conservation program in industry must not be confined solely to the elimination or reduction of noise in the working environment. Greatest benefits may be expected to flow from an effective health education program. The following points should be kept in mind in the development of an industrial hearing program:

1. The hearing capacity of the worker should be established by pre-employment examinations.

2. There should be prompt medical care for all ear infections, as well as for all upper respiratory disorders.

3. Chronic infections should be corrected.

15. NUTRITION IN INDUSTRY

15.1 IN-PLANT FEEDING

It has been shown that a large share of the working population is not adequately nourished. The problem of improving the world's eating habits is a very complex one that involves agricultural, economic, and educational factors. The improvement of working efficiency of employees is not only possible, but has been demonstrated repeatedly in industry today through provision of educational programs of nutrition, adequate lunchroom facilities, mid-morning and mid-afternoon feedings, and other nutritional measures.

It must not be assumed, however, that between-meal feedings, or the provision of lunchroom facilities will automatically increase the working efficiency of employees. Qualified leadership, proper planning, adequate facilities, and sound administrative procedures are essential if desirable results are to be attained from the institution of an industrial nutrition program.

Some guiding principles in the development of a sound nutritional program in industry are as follows:

1. *Nutritious meals* of natural foods at prices the workers are accustomed to and can afford to pay should be conveniently available to all workers.

2. Any regular meal served in the

* C. Stewart Nash, "Industrial Loss of Hearing: Medical Aspects," *Industrial Medicine and Surgery*, Vol. 21, No. 4, April 1952, 171-173.

plant should contribute at least *one-third of the daily food requirements* of the worker.

3. *Between-meal feedings* of workers should be instituted in industrial organizations. Milk, fruit, and tomato juices are to be preferred as beverages. When other foods are served, they should be nutritious in character. Candy and soft drinks are not recommended for between-meal feedings.

4. The choice of foods served in industrial cafeterias or restaurants should be determined by a *trained dietitian or nutritionist*.

5. *Studies of workers' diets* should be made in order to plan menus to overcome deficiencies.

6. *Educational material* should be presented in connection with cafeteria service, lunches, and between-meal feedings to stimulate acceptance of the meals planned.

7. The use of *specific nutritional measures* to prevent disease in certain occupations is advisable.

8. *An adequate amount of time should be allowed* for lunch; 30 minutes or less is not sufficient.

9. *Adequate lunchroom facilities* should be provided for workers; canteens and restaurants, when present, should be adequate.

15.2 EDUCATIONAL PROGRAM

A general educational program in nutrition should be part of whatever health education is carried on. The program should be nontechnical and should emphasize the practical selection of foods. The average person can be reasonably sure of securing a well-balanced diet if he is well informed in the general field of nutrition and if he follows certain accepted guides. The Council on Foods and Nutrition of the American Medical Association has approved the following *daily guide* prepared by the National Dairy Council:

1. MILK—Two or more glasses daily for adults. Three to four glasses for children. May be taken alone or in combination with other foods.
2. VEGETABLES—Two or more servings daily in addition to potatoes. One raw vegetable daily: green or yellow in color.
3. FRUITS—Two or more servings daily. One citrus fruit or tomato daily.
4. EGGS—One a day preferred, but at least 3 to 5 a week.
5. MEAT, CHEESE, FISH, OR LEGUMES—One or more servings daily.
6. CEREAL OR BREAD—Most of it whole grain or "enriched."
7. BUTTER—Two or more tablespoons daily.

16. THE CONTROL OF COMMUNICABLE DISEASES

Neither the rank and file employee nor the business executive is able to carry on the normal obligations of his occupation with top efficiency when he is suffering from a communicable disease. The degree to which the worker is incapacitated depends upon the illness from which he is suffering, upon his native or acquired resistance, and upon certain other factors. Both from the standpoint of personal health and occupational service or production it is important that we understand the principles of contagion and how we can control the spread of communicable disease.

16.1 CONTROL OF DISEASE

The control of communicable disease requires a good deal of information. Knowledge of the following factors is essential if the problem is to be recognized and controlled:

1. Specific cause of the disease.
2. Source of the infection.
3. Method in which the infection is spread.
4. The period of incubation.
5. The period of communicability.
6. Specific methods of control.

16.2 OCCUPATIONAL IMPLICATIONS

Since the control of communicable disease is largely a medical and public health problem, the physician and the health officer must be the primary source of guidance for industry in this regard.

There are certain measures and activities, however, that labor and management may foster to bring about greater control over this problem. Some of these are as follows:

16.2.1 Training of foremen, supervisors, and other minor executives in the symptoms of infections. This training should not suggest diagnoses, but only indications for referral of sick employees to family or industrial physicians in order that other workers may be protected and absenteeism reduced.

16.2.2 Isolation of sick employees. Workers who give evidence of infection should be isolated at once in order that other workers may be protected. Management should provide facilities and channels of administrative procedure to accomplish such isolation until the worker is put under medical guidance.

16.2.3 Exclusion from work. An employee suffering from a communicable disease should be excluded from work on order of the family or industrial physician, or other administrative personnel, until the employee is no longer a hazard to others.

16.2.4 Permit for return to work. Employees often return to work before they have fully recovered from infections. In such cases, other workers may be exposed, and the sick employee's health may be further impaired. A permit to return to work should be issued by the physician in control of the case, indicating that the patient is no longer in a communicable stage of the infection.

16.2.5 Immunizations. Management and labor should require as many immunizations of workers as appear practical and valuable in terms of the specific job to be done. Smallpox vaccinations should be a routine requirement, and immunizations for typhoid fever, typhus fever, tetanus, yellow fever, and other diseases should be required when needed. Immunization against influenza is a most important requirement in the control of this communicable disease during an epidemic.

16.2.6 Health education. Industry can profit from the support of general instruction in hygiene, including that part dealing with communicable diseases, but management and labor leadership have a particular responsibility to instruct workers in the hazards of infections that are related specifically to the type of work being done.

16.2.7 Special studies. Participation by labor and management in special studies for the detection of communicable diseases is an effective way of controlling the spread of certain infections. Mass chest surveys for the discovery of tuberculosis often turn up active, unsuspected cases. Obviously, the reduction of exposure to other workers and the proper treatment of the infected employee are profitable arrangements for both labor and management.

Communicable disease	*Occupations*
1. Anthrax	Butchers, farmers, fur workers, tannery workers, and veterinarians.
2. Rocky Mountain Spotted Fever	Foresters, hunters, sheep herders, and trappers.
3. Rabies	Dog-pound workers, mailmen, and veterinarians.
4. Psittacosis	Bacteriologists, parrot and parakeet handlers, and pet-shop owners.
5. Tuberculosis	Medical students, nurses, and physicians.

16.3 OCCUPATIONAL INFECTIONS

In certain occupations, specific infections are likely to develop. Although most infections of workers are *not* specifically related to occupation, there are some types of work in which there is exposure to one or more communicable disease hazards. Five examples are given in the list on page 767 to illustrate the principle that *every occupation must be investigated for its special dangers of infection.*

17. HEART DISEASE IN INDUSTRY

Because the leading cause of death in the United States is heart disease, and because hundreds of thousands of workers and members of workers' families are afflicted with cardiac disorders, there is ample justification for special attention to this problem.

It can be assumed automatically that in any large group of employees a certain number of workers will have heart disease. In such cases, the problem is primarily one of adjusting the physical and emotional capacity of the worker to the job to be done or adjusting the work to the capacities of the individual. In other words, it may be necessary to shift the worker to a lighter type of activity, or, if possible, it may be wise to adjust the work in which the employee is engaged to the capacity of the worker.

Matching the worker's physical capacities to the demands of the job calls for technical judgment and decision. The degree of incapacity caused by the illness must be appraised by a physician. The physical demands of the job must also be appraised, at least in part, by a physician. Once a careful study of both has been made, it should be possible to bring the two together.

Edmonds and Feil * have shown from a study of 300 cases of heart disease among the employees of the Erie Railroad Company over a 12-year period that nearly one-third of the men with heart disease could continue work for an extended period of time. In this study, 28 per cent of the men were still working at the end of 12 years. Many of the employees were able to carry out their jobs successfully for 10 to 15 years. By adjusting the work to be done to the capacity of the employee, many valuable workers can be saved for an extensive period of time even though they are suffering from heart disease.

The prevention of heart disease is largely a matter of health education. There are many different causes of heart disease, and when workers are well informed on these causes it is frequently possible for them to avoid injury to the heart.

An interesting plan for bringing a worker with heart disease to the kind of work that he can handle successfully has been reported. A special unit of the New York University Cardiac Clinic of the Bellevue Hospital, known as the Work Classification Unit, is gathering data on the effect of occupation on heart disease and is actively participating in the proper placement of workers with heart disorders. In this unit, a physician, a job analyst, and a trained employment placement officer coordinate their activities to achieve a proper matching of worker and job. A program for controlling heart disease in industry could well be based upon the following points:

1. *A classification of jobs* in terms of intensity of effort required should be made.
2. *A periodic medical examination* of employees should give information about the cardiac status of the worker.
3. When it is found that an employee has a heart disorder, his work responsibility should be appraised in order to achieve an effective *matching of work and capacity*.
4. *A program in health education* should be conducted which emphasizes the care of the heart.

* R. W. Edmonds and Harold Feil, "Cardiovascular Problems in Railroad Industry," *Industrial Medicine*, Vol. 17, No. 1, January 1948, 7-8.

18. ALCOHOL IN INDUSTRY

Periodic intoxication is a major cause of worker absences and impaired efficiency while on the job in many industries. Management and labor will have a difficult time in controlling this problem until more is known about both the cause and the cure of alcoholism, but there are some things that can be done to assist the individual in overcoming this undesirable habit. However, it must be emphasized that this condition is primarily a personal problem and one that can be overcome only by the individual himself. Assistance from others, however, is often a major factor in bringing about control of excessive drinking.

18.1 SYMPATHETIC ATTITUDES

Both management and labor leadership should realize that alcoholism is a disease and that the alcoholic is a sick person who needs help. Sympathetic, but not indulgent, attitudes on the part of both may help the excessive drinker to better self-control. Worthwhile employees should not be dismissed impulsively because of intoxication. Rather, a careful study of the basic causes underlying the excessive drinking should be made in order that more adequate aid may be extended the alcoholic. This is especially true if the drinker is a valuable employee.

18.2 REGULATIONS AGAINST WORKING WHILE INTOXICATED

Sensible regulations, adequately enforced, should protect workers from hazards created by other employees who are intoxicated on the job.

18.3 ALCOHOL EDUCATION

Both management and labor leadership should conduct continuous educational programs to inform employees of the effects of alcohol and of resources for treatment that are available to the employee who desires help. This instruction should deal with scientific evidence and should be on a practical plane that elicits respect from the worker. Much alcohol education of the past has had little appeal to employees.

18.4 COOPERATION WITH ALCOHOLICS ANONYMOUS

This organization has given good evidence that it can contribute important help to alcoholics. A growing number of confirmed addicts have been completely cured for a number of years with the aid of Alcoholics Anonymous. Good results are secured only when the alcoholic himself seeks help; so industry's part in this problem should be to inform all workers of the activities of this organization and to cooperate actively with it, rather than to force or entice drinkers to join the group.

18.5 HOSPITALIZATION FOR ACUTE ALCOHOLISM

A few hospitals are beginning to accept the alcoholic patient as a sick person who needs medical care. This practice should be encouraged by industry. An important part of the alcohol cure is prompt medical treatment in the first few days after alcoholic excesses. In those hospitals or infirmaries operated by a particular industrial organization, provision should be made for the medical treatment of the acutely intoxicated worker.

The Eastman Kodak Company of Rochester, New York, is a good example of an industrial organization that has given special attention to the problem of the alcoholic employee.* This com-

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* John L. Norris, "Alcoholism in Industry," *Quarterly Journal of Studies on Alcohol,* Vol. 11, No. 4, December 1950, 562-566.

pany has entered into a cooperative enterprise involving medicine, psychiatry, social agencies, law-enforcement agencies, and Alcoholics Anonymous.

Whenever a warrant is sworn out for public intoxication of a worker, it is served by a special police officer assigned to work with alcoholics. The officer is himself a member of the local group of Alcoholics Anonymous. He first visits the family, then the employer, and finally the alcoholic worker. The understanding way in which the case is handled often serves as an effective introduction to the Alcoholics Anonymous organization and to the beginning of rehabilitation.

This community approach has been of definite value to the industrial situation in terms of more satisfactory treatment and adjustment of alcoholic employees.

19. SKIN DISORDERS IN INDUSTRY

It is estimated by some authorities in the field of industrial hygiene that more than $100,000,000 annually is lost in the United States because of occupational skin disorders. According to Schwartz,* occupational diseases of the skin constitute about 60 per cent of all reported industrial diseases.

In California during 1950, out of 12,245 cases of occupational disease, well over 6,000 were due to diseases of the skin from poison oak, oils, greases, solvents, chemicals, industrial poisonings, and other diseases.

So far as industry itself is concerned, the most effective prevention of skin disease is to have effective control of irritating substances in the work environment. Any company that uses chemicals in its industrial processes should be especially careful, since these are the most common source of occupational skin disease. In some industries it is possible to conduct operations that are totally enclosed. Such measures provide effective control over irritating chemicals. Use of protective clothing, ointments, clean work clothes, and other devices also assist in the control of occupational skin disorders.

* Louis Schwartz, "Hundred Million Dollar Loss," *National Safety News*, Vol. 65, No. 2, February 1952, 33 ff.

All skin disorders, however, that disable the worker do not originate on the job. Lost time and temporary impairment of efficiency may be caused by poison oak encountered on week-end picnics. Health education of the worker in respect to protection of the skin from a variety of damaging influences is important.

20. HEALTH IN THE WORKER'S FAMILY

Family life can have a favorable or unfavorable influence on health. *The health of each member, good or bad, has its effect upon all other members of the family.* All health problems in the family are intensified by the close and intimate association of its members. Any consideration of the worker's health cannot be complete unless attention is given to the health of his family, and to how this affects his working efficiency. The occupational hygiene program should utilize family resources to the utmost in efforts to improve the health and welfare of the employee.

The Jones and Laughlin Steel Corporation is an example of an industrial organization that is active in helping the worker to find a solution to home problems.* The experience of this company indicates that behavior and emotional problems of the wife or children of the worker constitute the main type of difficulty for which aid and guidance are rendered. In this organization, it is felt that a definite contribution, especially to the mental health of the workers, is being made by the industrial health program that gives attention to the problems of the family, as well as to those of the worker himself.

* Carl W. Gatter, "The Industrial Physician and the Workers' Home Problems," *Industrial Medicine and Surgery*, Vol. 21, No. 6, June 1952, 273-276.

21. RECREATION AND HEALTH

Recreation does have a relationship to human health, both mental and physical, but it must not be assumed that health benefits flow automatically from the provision of recreational activities.

Athletic programs for workers, for example, may be good or bad, depending on their suitability to the age and capacities of the employees. Injuries resulting from athletics are sometimes an important cause of worker absence or reduced efficiency. Experts in the field of physical education have long ago learned that an effective safety program must accompany physical activities if the health of the participant is to be protected.

Recreational activities should be provided only after a careful survey has been made of employee preferences. It should not be assumed that all worker groups will be interested in the same type of activities.

Boothe,* for example, studied the recreational preferences of a group of 250 employees in the electrical, automotive, and rubber industries and found that there was a wide range of interests among this group. The top 20 preferences in this study are listed below in rank order, with the percentage of the individuals desiring to participate in the activities rounded to the nearest whole number.

Activity	*Percentage*
1. Bowling	41
2. Fishing	37
3. Hunting	36
4. Basketball	34
5. Rifle-Pistol	33
6. Baseball	32
7. Golf	30
8. Softball	24
9. Automobile riding	24
10. Swimming	24
11. Billiards	20
12. Horseshoes	17
13. Cards	16
14. Boxing	14
15. Skeet shooting	13
16. Social dancing	12
17. Bait-casting	10
18. Roller-skating	10
19. Tennis	10
20. Camera club	10

* Leroy E. Boothe, "A Study of Industrial Recreational Activities in Lafayette, Indiana," *Research Quarterly*, Vol. 14, No. 1, March 1943, 125-128.

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Albert Hosmer Bowker, Director of the Applied Mathematics and Statistics Laboratory and Professor of Mathematics and Statistics, Stanford University, is one of the outstanding young men in mathematical statistics in this country. After receiving a bachelor's degree from the Massachusetts Institute of Technology in 1941, he was a Research Assistant in the Mathematics Department of the same Institute, and later moved to Columbia University. There he was Associate Mathematical Statistician and later Assistant Director of the Statistical Research Group of the Applied Mathematics Panel, OSRD.

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Dr. Lieberman is the author of a number of technical reports issued by the Applied Mathematics and Statistics Laboratory of Stanford University, and has contributed articles to the *Journal of the American Statistical Association* and the *Annals of Mathematical Statistics*.

Industrial Statistics

future observation y^* corresponding to x^* will lie. 5.7 Correlation. 5.8 Relations between several variables. 5.9 Test of significance. 5.10 Nonlinear regression. 5.11 Example.

6. ANALYSIS OF VARIANCE. 6.1 Introduction. 6.2 One-way classification. 6.3 Two-way classification. 6.4 Two-way classification—one observation per cell and no interaction assumed. 6.5 Two-way classification—more than one observation per cell—interaction. 6.6 Three-way classification. 6.7 Latin square. 6.8 Components of variance model. 6.9 Hartley's test for homogeneity of variances.

7. ANALYSIS OF ENUMERATION DATA—CHI-SQUARE TESTS. 7.1 Introduction. 7.2 The hypothesis completely specifies the relative frequencies of the categories. 7.3 Test of independence in a two-way classification. 7.4 Computing form for test of independence in a 2 by 2 table. 7.5 Comparison of two percentages.

1. BASIC STATISTICAL CONCEPTS

1.1 INTRODUCTION

The science of statistics deals with drawing conclusions from observed data; the popular conception of statistics is that it involves large masses of data and concerns itself with percentages, averages, or presentation of data in tables or charts. This represents only a small part of the field today and is of less interest to industrial engineers than are other aspects of statistics—e.g., quality control, sampling inspection, and the design and analysis of experiments. These latter topics are the major ones presented in this section.

Most scientific investigations, whether concerned with the effect of a new drug on polio, methods of allaying traffic congestion in a big city, consumer reaction to a new product, or the quality of manufactured products, depend on observations, even if they are of a rudimentary sort. In scientific and industrial experimentation, these observations are taken to study the effect of variation of certain factors or the relation between certain factors. One may wish to study the quality of a raw material from a new supplier, the relation between tensile strength and hardness for a particular alloy, or the optimum combination of conditions in a manufacturing process. Ultimately, these observations are to be used for making decisions; the remainder of this section deals with providing procedures for making decisions with preassigned risks on the basis of the limited information in samples. These procedures are illustrated by examples. Many of these examples contain published data with references to the source.

1.2 EMPIRICAL DISTRIBUTIONS AND HISTOGRAMS

A basic notion of statistics is the notion of variation. For example, there is no single figure for the life of all incandescent lamps produced under certain conditions; some may last many times as long as others. Consider, for example, the data in Table 13.1 on the lifetimes in hours of 417 40-w 110-v internally frosted incandescent lamps taken from forced life tests.* The life

* D. J. Davis, "An Analysis of Some Failure Data," *Journal of the American Statistical Association*, Vol. 47, 1953.

varies from a low of 225 hr to a maximum of 1690. Many factors including variations in raw materials, workmanship, function of automatic machinery, and, in fact, test conditions may account for these differences; some of these factors may be controlled carefully but some pattern of variation is inherent in all observational data. Perhaps no one would expect all light bulbs to have exactly the same life, but even the results of the most carefully controlled experiments, such as those designed to measure the velocity of light, exhibit variation due to experimental error. Returning to the light bulbs, the data

TABLE 13.1 ITEM LIFETIMES FOR INCANDESCENT LAMPS

Date	Item lifetimes										Average of sample
1-2-47	1067	919	1196	785	1126	936	918	1156	920	948	997
1-9-47	855	1092	1162	1170	929	950	905	972	1035	1045	1012
1-16-47	1157	1195	1195	1340	1122	938	970	1237	956	1102	1121
1-23-47	1022	978	832	1009	1157	1151	1009	765	958	902	978
1-30-47	923	1333	811	1217	1085	896	958	1311	1037	702	1027
2-6-47	521	933	928	1153	946	858	1071	1069	830	1063	937
2-13-47	930	807	954	1063	1002	909	1077	1021	1062	1157	998
2-20-47	999	932	1035	944	1049	940	1122	1115	833	1320	1029
2-27-47	901	1324	818	1250	1203	1078	890	1303	1011	1102	1088
3-6-47	996	780	900	1106	704	621	854	1178	1138	951	923
3-13-47	1187	1067	1118	1037	958	760	1101	949	992	966	1014
3-20-47	824	653	980	935	878	934	910	1058	730	980	888
3-27-47	844	814	1103	1000	788	1143	935	1069	1170	1067	993
4-3-47	1037	1151	863	990	1035	1112	931	970	932	904	993
4-10-47	1026	1147	883	867	990	1258	1192	922	1150	1091	1053
4-17-47	1039	1083	1040	1289	699	1083	880	1029	658	912	971
4-23-47	1023	984	856	924	801	1122	1292	1116	880	1173	1017
5-1-47	1134	932	938	1078	1180	1106	1184	954	824	529	986
5-8-47	998	996	1133	765	775	1105	1081	1171	705	1425	1015
5-15-47	610	916	1001	895	709	860	1110	1149	972	1002	922
5-22-47	990	1141	1127	1181	856	716	1308	943	1272	917	1045
5-29-47	1069	976	1187	1107	1230	836	1034	1248	1061	1550	1130
6-5-47	1240	932	1165	1303	1085	813	1340	1137	773	787	1058
6-12-47	1438	1009	1002	1061	1277	892	900	1384	1148		1123
6-19-47	1117	1225	1176	709	1485	1225	1011	1028	1227	1277	1148
6-26-47	1222	912	885	1562	1118	1197	976	1080	924	1233	1111
7-3-47	1135	623	983	883	1088	1029	1201	898	970	1058	987
7-10-47	1160	831	1023	1354	1218	1121	1172	1169	1113	1308	1147
7-17-47	1166	1470	1635	1141	1555	1054	1461	1057	1228	1187	1295
8-7-47	1016	744	1197	1122	666	1022	964	1085	612	1003	943
8-14-47	1235	942	1055	893	1235	1056	968	1056	1014	1096	1055
8-21-47	1013	889	1430	926	1297	1033	1024	1103	1385		1122
8-28-47	1077	813	1121	960	1156	1033	1255	225	525	675	884
9-4-47	1211	995	924	732	935	1173	1024	1254	1014		1029
9-11-47	798	1080	862	1220	1024	1170	1120	898	918	1086	1018
9-18-47	1028	1122	872	826	1337	965	1297	1096	1068	943	1055
9-25-47	1490	918	609	985	1233	985	985	1075	1240	985	1051
10-2-47	1105	1243	1204	1203	1310	1262	1234	1104	1303	1185	1215
10-9-47	759	1404	944	1343	932	1055	1381	816	1067	1252	1095
10-16-47	1248	1324	1000	984	1220	972	1022	956	1093	1358	1118
10-23-47	1024	1240	1157	1415	1385	824	1690	1302	1233	1331	1260
10-30-47	1109	827	1209	1202	1229	1079	1176	1173	769	905	1068

in Table 13.1 recorded serially do not present a clear picture of the nature of the variation, and it is more useful to present the data in a frequency table (Table 13.2), grouping adjacent observations into classes, which are usually called class intervals or cells.

TABLE 13.2 FREQUENCY TABLE FOR LENGTH OF LIFE OF INCANDESCENT LAMPS

Class interval (*100 hr*)	*Frequency* (*f*)	*Mid-point of class interval* (*m*)	*Deviation from arbitrary origin* (*1050*) *in class intervals* (*d*)	*fd*	*fd²*
200–299	1	250	−8	−8	64
300–399	...	350	−7	...	...
400–499	...	450	−6	...	...
500–599	3	550	−5	−15	75
600–699	10	650	−4	−40	160
700–799	21	750	−3	−63	189
800–899	43	850	−2	−86	172
900–999	91	950	−1	−91	91
1000–1099	87	1050	0	0	0
1100–1199	79	1150	1	79	79
1200–1299	44	1250	2	88	176
1300–1399	24	1350	3	72	216
1400–1499	9	1450	4	36	144
1500–1599	3	1550	5	15	75
1600–1699	2	1650	6	12	72
Totals	417			−1	1513

Calculations

1. Raw data

(a) Mean: $\bar{x} = \dfrac{\sum_{i=1}^{N} x_i}{N} = \dfrac{435{,}921}{417} = 1{,}045.37$

(b) Standard deviation:

$$s^2 = \frac{\sum (x_i - \bar{x})^2}{N-1} = \frac{\sum x_i^2 - (\sum x_i)^2/N}{N-1}$$

$$= \frac{470{,}808{,}333 - 190{,}027{,}118{,}241/417}{416} = 36{,}316.85$$

$$s = 190.57$$

2. Grouped data

(a) Mean:

$\bar{x}$ in class intervals from arbitrary origin of 1050 $\dfrac{\sum fd}{N}$

$$= -0.002$$

$$\bar{x} \text{ in original units} = \text{arbitrary origin} + \frac{\sum fd}{N} (\text{class interval})$$

$$= 1050 - 0.002(100) = 1050$$

(b) Standard deviation:

$$s \text{ in class interval units} = \sqrt{\frac{\sum fd^2 - (\sum fd)^2/N}{N-1}}$$

$$\sqrt{\frac{1513 - (1)^2/417}{416}} = 1.91$$

$$s \text{ in original units} = s \text{ in class interval units (class interval)}$$
$$= 1.91$$

The most common method of presenting graphically such data as Table 13.1 is in terms of a histogram (Fig. 13.1), which consists of a number of columns with sides equal to the class interval boundaries and height proportional to the frequency.

For comparative or summary purposes, it is often useful to describe an observed frequency distribution by one or two numbers; the most common method is to use the arithmetic mean, which is a measure of central tendency and the sample standard deviation, which is a measure of dispersion around the mean. The calculation of the mean and standard deviation from both the raw data and the grouped data are illustrated in Table 13.2.* For small

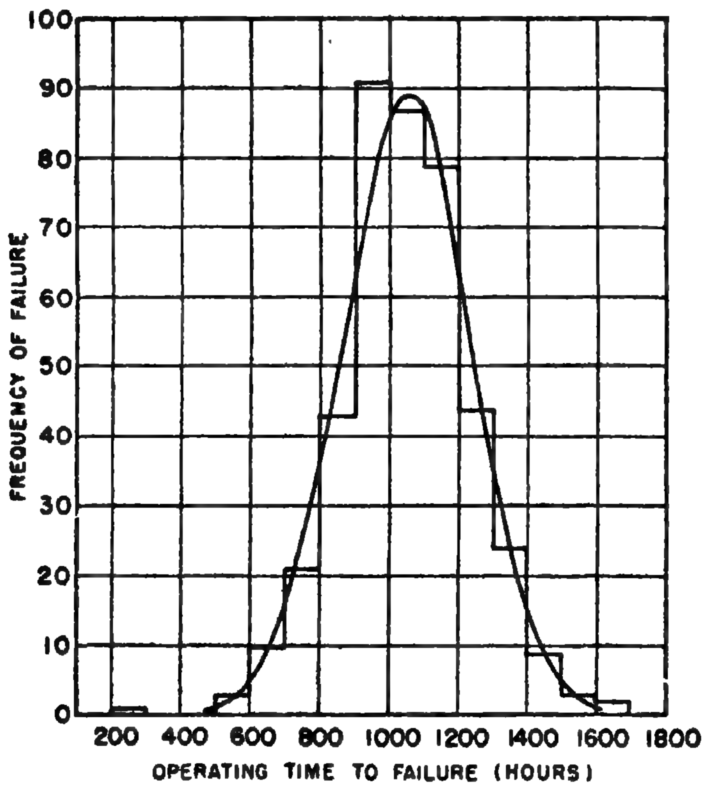

FIG. 13.1 LIFE LENGTH HISTOGRAM FOR INCANDESCENT LAMPS.

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* Throughout this section terms such as $x_1 + x_2 + x_3 + x_4 + x_5$ will be represented as $\sum_{i=1}^{5} x_i$. When no confusion exists, this may instead be written as $\sum x_i$. Terms such as $x_{11} + x_{12} + x_{13} + x_{14} + x_{21} + x_{22} + x_{23} + x_{24} + x_{31} + x_{32} + x_{33} + x_{34}$ will be represented as $\sum_{i=1}^{3} \sum_{j=1}^{4} x_{ij}$.

numbers of observations, grouped data computations are not usually advantageous.

1.3 THEORETICAL DISTRIBUTIONS

In the preceding article we described the concept of variables and the presentation of a large volume of data in the form of a histogram. Many decisions from observed data are based on small samples that are assumed to be drawn at random from a larger source, a so-called parent universe or population. To make valid inferences on the basis of small samples it is necessary to make some assumptions about the form of this population.

It is worth while to introduce here an important notion about these models; the constants that characterize these populations are called parameters and should always be clearly distinguished from the quantities we calculate from the observations, i.e., statistics. Thus the statistic, the arithmetic mean of a sample, may differ from the parameter, the true mean value* of the population.

1.3.1 Normal distribution. The most important distribution in statistics is the normal distribution. This distribution has a symmetric bell-shaped form and tends to infinity in both directions. One of the classical theorems of probability states in essence that if observed quantities can be considered to be the result of large numbers of additive chance effects, the distribution of these quantities should be approximately normal. This theory, plus a mass of empirical evidence, indicates that the normal distribution may be assumed as the underlying population for a large number of industrial problems.

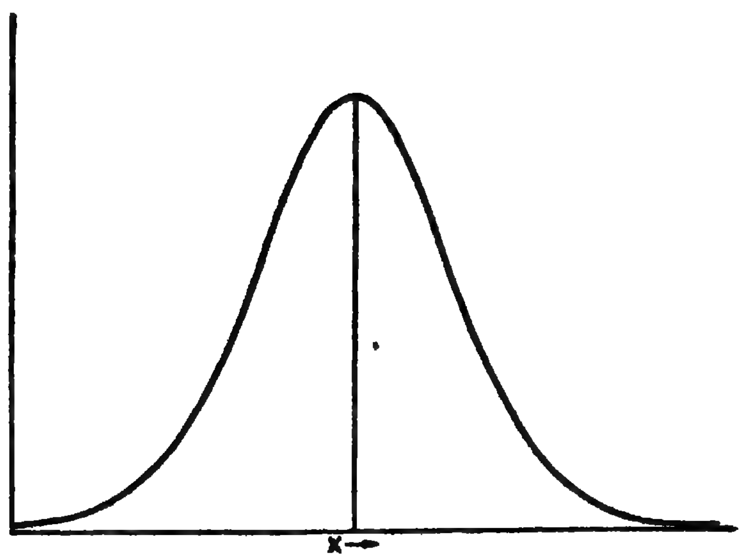


FIG. 13.2 NORMAL DISTRIBUTION.

* If $f(x)$ represents the equation for the probability distribution, the true mean or population mean given by $\mu = \int_{-\infty}^{+\infty} xf(x)\,dx$ is a parameter.

The equation for the normal curve is

$$\frac{1}{\sqrt{2\pi}\,\sigma}\, e^{-(x-\mu)^2/2\sigma^2}$$

The area under the curve is 1. The curve is determined by the two parameters μ, the population mean, and σ, the population standard deviation.*

The normal curve in standard form has area equal to 1, but it is sometimes desirable to construct a normal distribution which has the same area as a histogram. In this case, we write the equation

$$\frac{Nw}{\sqrt{2\pi}\,\sigma}\, e^{-(x-\mu)^2/2\sigma^2}$$

where N is the total number of observations and w is the width of the class interval.

Areas of the normal distribution may be found in Table 13.3.

Most of the techniques of analysis presented in the remaining articles depend on the distribution of statistics based on random samples from a normal distribution. The sample mean has a normal distribution; in fact, for large samples the distribution of the sample mean from any distribution will be approximately normal. Other distributions, the chi-square, the t distribution, and the F distribution, are the distributions of various functions of means and variances of samples from a normal distribution. The explicit forms of these distributions need not concern us.

1.3.2 **The binomial distribution.** If we have a series of n independent trials and if at each trial p is the probability that the event will occur, the probability that r events occur in the n trials is $\binom{n}{r}p^r q^{n-r}$, where $q = 1 - p$, and $\binom{n}{r}$ is the number of combinations of n things taken r at a time.

$$\binom{n}{r} = \frac{n!}{r!(n-r)!} \quad \text{and} \quad n! = n(n-1)(n-2)\ldots(3)\,(2)\,(1)$$

The most common application in industrial work is lot-by-lot acceptance inspection, where the lot is large compared with the sample size; p is the fraction defective in the lot, n is the size of a sample drawn at random from the lot, and r is the observed number of defectives.

The observed number of defectives is some number from 0 to n, and hence

$$\sum_{r=0}^{n} \binom{n}{r} p^r q^{n-r} = 1$$

---

* $\frac{1}{\sqrt{2\pi}\,\sigma}\int_{-\infty}^{+\infty} e^{-(x-\mu)^2/2\sigma^2}\,dx = 1;\quad \frac{1}{\sqrt{2\pi}\,\sigma}\int_{-\infty}^{+\infty} xe^{-(x-\mu)^2/2\sigma^2}\,dx = \mu;$

$$\frac{1}{\sqrt{2\pi}\,\sigma}\int_{-\infty}^{+\infty} (x-\mu)^2 e^{-(x-\mu)^2/2\sigma^2}\,dx = \sigma^2$$

TABLE 13.3 AREAS UNDER THE NORMAL CURVE FROM K_α TO ∞*

$$\int_{K_\alpha} \frac{1}{\sqrt{2\pi}} e^{-x^2/2}\, dx = \alpha$$

K_α	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641
0.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
0.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
0.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
0.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
0.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
0.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
0.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
0.8	.2119	.2090	.2061	2033	.2005	.1977	.1949	.1922	.1894	.1867
0.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
1.4	.0808	.0793	.0778	0764	.0749	.0735	.0721	.0708	.0694	.0681
1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	0183
2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
2.3	.0107	.0104	.0102	.00990	.00964	.00939	.00914	.00889	.00866	.00842
2.4	.00820	.00798	.00776	.00755	.00734	.00714	.00695	.00676	.00657	.00639
2.5	.00621	.00604	.00587	.00570	.00554	.00539	.00523	.00508	.00494	.00480
2.6	.00466	.00453	.00440	.00427	.00415	.00402	.00391	.00379	.00368	.00357
2.7	.00347	.00336	.00326	.00317	.00307	.00298	.00289	.00280	.00272	.00264
2.8	.00256	.00248	.00240	.00233	.00226	.00219	.00212	.00205	.00199	.00193
2.9	.00187	.00181	.00175	.00169	.00164	.00159	.00154	.00149	.00144	.00139

K_α	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
3	.00135	$.0^{3}968$	$.0^{3}687$	$.0^{3}483$	$.0^{3}337$	$.0^{3}233$	$.0^{3}159$	$.0^{3}108$	$.0^{4}723$	$.0^{4}481$
4	$.0^{4}317$	$.0^{4}207$	$.0^{4}133$	$.0^{5}854$	$.0^{5}541$	$.0^{5}340$	$.0^{5}211$	$.0^{5}130$	$.0^{6}793$	$.0^{6}479$
5	$.0^{6}287$	$.0^{6}170$	$.0^{7}996$	$.0^{7}579$	$.0^{7}333$	$.0^{7}190$	$.0^{7}107$	$.0^{8}599$	$.0^{8}332$	$.0^{8}182$
6	$.0^{9}987$	$.0^{9}530$	$.0^{9}282$	$.0^{9}149$	$.0^{10}777$	$.0^{10}402$	$.0^{10}206$	$.0^{10}104$	$.0^{11}523$	$.0^{11}260$

* Reprinted by permission from Frederick E. Croxton, *Elementary Statistics with Applications in Medicine* (New York: Prentice-Hall, Inc., 1953), p. 323.

For example, suppose $n = 18$, $p = 0.10$.

r	Probability of r defectives
0	0.150
1	0.300
2	0.284
3	0.168
4	0.070
5	0.022
6	0.005
7	0.001
8	0.000
.	.
.	.
.	.
18	0.000

The distribution function of the above binomial distribution function is plotted in Fig. 13.3.

2. STATISTICAL QUALITY CONTROL: CONTROL CHARTS

2.1 INTRODUCTION

In his book *Statistical Quality Control*, Eugene L. Grant★ states: "Measured quality of manufactured product is always subject to a certain amount of variation as a result of chance. Some stable 'system of chance causes' is inherent in any particular scheme of production and inspection. Variation within this stable pattern is inevitable. The reasons for variation

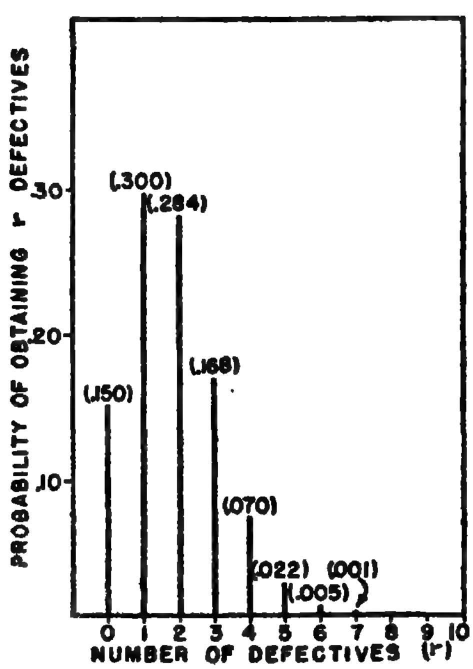


FIG. 13.3 DISTRIBUTION FUNCTION FOR THE BINOMIAL DISTRIBUTION WITH $n = 18$ AND $p = 0.10$.

★ *Statistical Quality Control*, 2nd ed. (New York: McGraw-Hill Book Company Inc., 1952), p. 3.

outside this stable pattern may be discovered and corrected. . . ." These variations outside the stable pattern are known as *assignable causes* of quality variation. A process operating in the absence of any assignable causes of erratic fluctuations is said to be in *statistical control.*

To the manufacturer, the primary purpose of the control chart is to provide a basis for *action*. The introduction of a control chart aids in determining the capabilities of the production process. Action is taken when these estimated capabilities are unsatisfactory in relation to the design specifications. Furthermore, once the process capabilities have been determined, and are satisfactory, action is taken only when the control chart indicates that the process has fallen out of control, e.g., assignable causes of variation have entered.

2.2 OBTAINING DATA FROM RATIONAL SUBGROUPS

The essential feature of the control chart method is the drawing of inferences about the production process on the basis of samples drawn from the production line. The success of the technique depends upon grouping observations under consideration into subgroups or samples, within which a stable system of chance causes is operating, and between which the variations may be due to assignable causes whose presence is suspected or considered possible. Order of production is one of the more commonly used bases for obtaining rational subgroups. If items are coming from more than one source, the source may be a basis for rational subgrouping.

The size of the subgroup or sample usually is not less than 4. In industry 5 seems to be the most common.* It is preferable that all samples be of equal size.

2.3 CONTROL CHARTS FOR VARIABLES: $\bar{x}$ CHARTS

2.3.1 Statistical concepts. If observations on an item are normally distributed, with mean $\bar{x}'$ and standard deviation σ', it is possible to find the probability that an observation will lie in an interval by referring to Table 13.3. Furthermore, if we denote the variable by x, the probability that x will be within the interval $\bar{x}' \pm 3\sigma'$ is 0.9973. In other words, if a plot such as that in Fig. 13.4 is made, on the average only 27 observations out of 10,000 will be outside the above interval, if the *population mean is $\bar{x}'$ and the population standard deviation is σ'*.† If the underlying population is normal with mean $\bar{x}'$ and standard deviation σ', the population of averages of subgroups of n drawn from the above population is also normal with mean $\bar{x}'$ and stand-

* When characteristics are classified into two groups, those containing defects and those not containing defects, and no other measurement is recorded, the sample size is usually much larger.

† The notation in the articles on quality control is that recommended by the American Society for Quality Control. In the remaining articles, the usual notation found in texts on industrial statistics will be used—i.e., μ will represent the population mean, and σ will represent the population standard deviation.

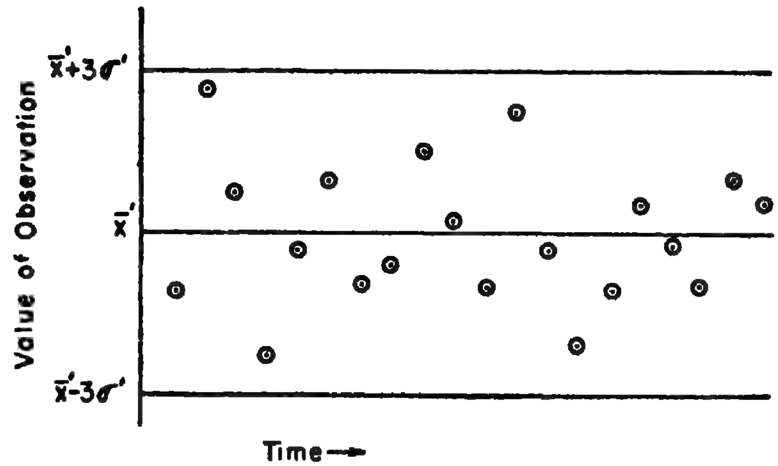


FIG. 13.4 PLOT OF INDIVIDUAL OBSERVATIONS.

ard deviation $\sigma'_{\bar{x}} = \sigma'/\sqrt{n}$. Denoting the n observations by $x_1, x_2, \ldots, x_n$, the average of these n observations, $\bar{x}$, is defined as

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n}.$$

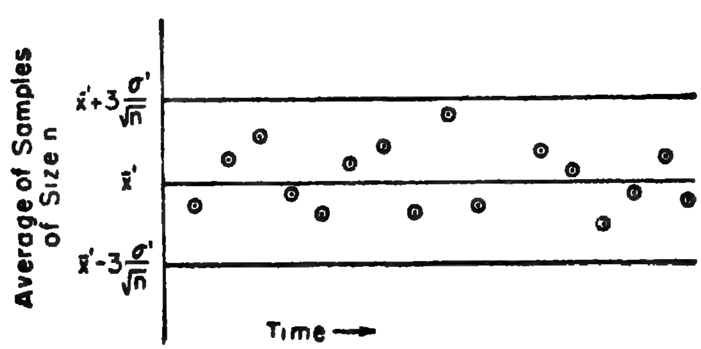
If instead of plotting individual values as in Fig. 13.4, averages of samples of n are plotted, it is expected that on the average only 27 in 10,000 values of these averages will fall outside the interval

$$\bar{x}' \pm 3\sigma'_{\bar{x}} = \bar{x}' \pm \frac{3\sigma'}{\sqrt{n}}$$

The plot in Fig. 13.5 is referred to as a control chart for $\bar{x}$. Here $\bar{x}' + 3\sigma'/\sqrt{n}$ is referred to as the upper control limit (UCL) while $\bar{x}' - 3\sigma'/\sqrt{n}$ is referred to as the lower control limit (LCL).

In all the above discussion it was assumed that the underlying distribution is normal. Although in actual practice many distributions of observations are "nearly" normally distributed, many others do not resemble a normal distribution at all. However, it can be shown that under fairly weak restrictions,

FIG. 13.5 CONTROL CHART FOR $\bar{x}$.



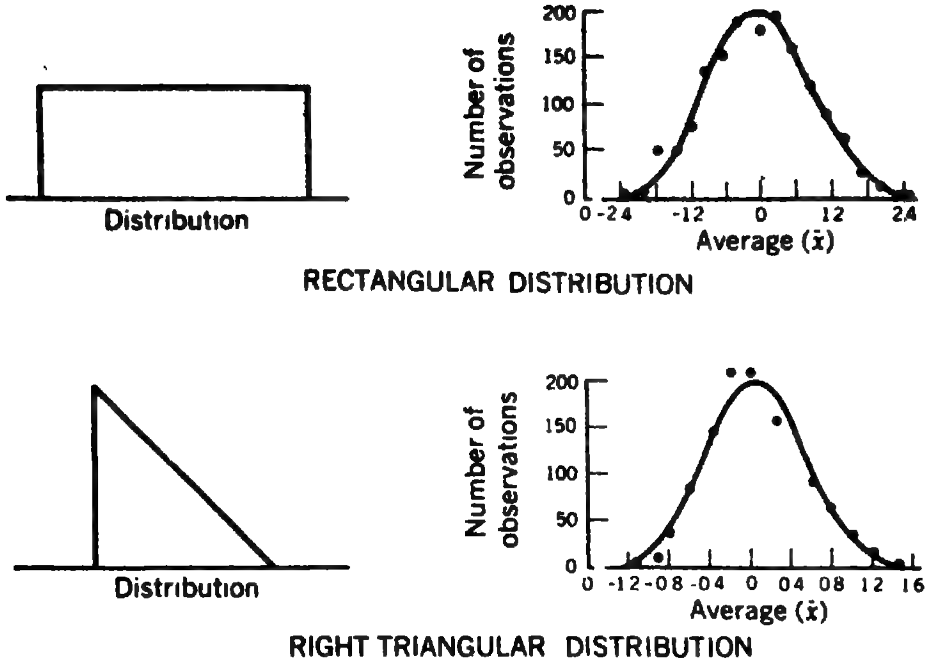


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FIG. **13.6** DISTRIBUTION OF THE SAMPLE AVERAGE FROM A RECTANGULAR UNIVERSE AND A RIGHT TRIANGULAR UNIVERSE.

the average of samples of n tend toward normality as n gets large. This theorem is called the central limit theorem, and a proof can be found in most standard texts in mathematical statistics.

From a practical point of view n need not be too large before the results of the theorem begin to apply. In Fig. 13.6, it is demonstrated that even when the underlying distribution is from a rectangular or a triangular distribution, the distribution of $\bar{x}$ values from samples of 4 is approximately normal.

It is evident, then, that the central limit theorem is one of the keys to the success of the control chart for $\bar{x}$. No matter what the underlying distribution may be (there are certain weak conditions that must be satisfied), the above theorem states that the theory about the properties of the normal distribution is applicable, provided, of course, sample averages are considered as the variable plotted on the control chart.

2.3.2 Estimates of $\bar{x}'$. In Fig. 13.5, a control chart for $\bar{x}$ is shown, where the control limits are drawn in as functions of $\bar{x}'$ and σ'. In most practical applications $\bar{x}'$ and σ' are not known, and consequently estimates of these parameters must be obtained. It is desirable that these estimates be based on at least 25 subgroups of n observations. Naturally, the larger the number of subgroups, the better the estimates of the population parameters, provided the process is in control. Suppose the estimates are based upon k subgroups of size n. Denoting the averages of the subgroups by $\bar{x}_1, \bar{x}_2, \ldots, \bar{x}_k$, the best

estimate of $\bar{x}'$, the population mean, is

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + \ldots + \bar{x}_k}{k}$$

where $\bar{\bar{x}}$ is also the average of all the nk observations.

2.3.3 **Estimate of σ' by $\bar{\sigma}$.** As was pointed out in the previous article, it is usually necessary to estimate σ', the population standard deviation. Define, for each subgroup:

$$\sigma = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2}{n}}$$

$$= \sqrt{\frac{x_1^2 + x_2^2 + \ldots + x_n^2 - n\bar{x}^2}{n}}$$

Let $\bar{\sigma}$ be the average of the standard deviations of the k subgroups, i.e.,

$$\bar{\sigma} = \frac{\sigma_1 + \sigma_2 + \ldots + \sigma_k}{k}$$

TABLE 13.4 FACTORS FOR COMPUTING CONTROL CHART LINES*

Number of observations in sample, n	Chart for averages			Chart for standard deviations							Chart for ranges						
	Factors for control limits			Factors for central line		Factors for control limits				Factors for central line		Factors for control limits				
	A	A_1	A_2	c_2	$1/c_2$	B_1	B_2	B_3	B_4	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	3.760	1.880	0.5642	1.7725	0	1.843	0	3.267	1.128	0.8865	0.853	0	3.686	0	3.267
3	1.732	2.394	1.023	0.7236	1.3820	0	1.858	0	2.568	1.693	0.5907	0.888	0	4.358	0	2.575
4	1.500	1.880	0.729	0.7979	1.2533	0	1.808	0	2.266	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	1.596	0.577	0.8407	1.1894	0	1.756	0	2.089	2.326	0.4299	0.864	0	4 918	0	2.115
6	1.225	1.410	0.483	0.8686	1.1512	0.026	1.711	0.030	1.970	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	1.277	0.419	0.8882	1.1259	0.105	1.672	0.118	1.882	2.704	0.3698	0.833	0.205	5.203	0.076	1.924
8	1.061	1.175	0.373	0.9027	1.1078	0.167	1.638	0.185	1.815	2.847	0.3512	0.820	0.387	5.307	0.136	1.864
9	1.000	1.094	0.337	0.9139	1.0942	0.219	1.609	0.239	1.761	2.970	0.3367	0.808	0.546	5.394	0.184	1.816
10	0.949	1.028	0.308	0.9227	1.0837	0.262	1.584	0.284	1.716	3.078	0.3249	0.797	0.687	5.469	0.223	1 777
11	0.905	0.973	0.285	0.9300	1.0753	0.299	1.561	0.321	1.679	3.173	0.3152	0.787	0.812	5.534	0.256	1.744
12	0.866	0.925	0.266	0.9359	1.0684	0.331	1.541	0.354	1.646	3.258	0.3069	0.778	0.924	5.592	0.284	1.716
13	0.832	0.884	0.249	0.9410	1.0627	0.359	1.523	0.382	1.618	3.336	0.2998	0.770	1.026	5.646	0.308	1.692
14	0.802	0.848	0.235	0.9453	1.0579	0.384	1.507	0.406	1.594	3.407	0.2935	0.762	1.121	5.693	0.329	1.671
15	0.775	0.816	0.223	0.9490	1.0537	0.406	1.492	0.428	1.572	3.472	0.2880	0.755	1.207	5.737	0.348	1.652
16	0.750	0.788	0.212	0.9523	1.0501	0.427	1.478	0.448	1.552	3.532	0.2831	0.749	1.285	5.779	0.364	1.636
17	0.728	0.762	0.203	0.9551	1.0470	0.445	1.465	0.466	1.534	3.588	0.2787	0.743	1.359	5.817	0.379	1.621
18	0.707	0.738	0.194	0.9576	1.0442	0.461	1.454	0.482	1.518	3.640	0.2747	0.738	1.426	5.854	0.392	1.608
19	0.688	0.717	0.187	0.9599	1.0418	0.477	1.443	0.497	1.503	3.689	0.2711	0.733	1.490	5.888	0.404	1.596
20	0.671	0.697	0.180	0.9619	1.0396	0.491	1.433	0.510	1.490	3.735	0.2677	0.729	1.548	5.922	0.414	1.586
21	0.655	0.679	0.173	0.9638	1.0376	0.504	1.424	0.523	1.477	3.778	0.2647	0.724	1.606	5.950	0.425	1.575
22	0.640	0.662	0.167	0.9655	1.0358	0.516	1.415	0.534	1.466	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.647	0.162	0.9670	1.0342	0.527	1.407	0.545	1.455	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.632	0.157	0.9684	1.0327	0.538	1.399	0 555	1.445	3.895	0.2567	0.712	1.759	6.031	0.452	1.548
25	0.600	0.619	0.153	0.9696	1.0313	0.548	1.392	0.565	1.435	3.931	0.2544	0.709	1.804	6.058	0.459	1.541
Over 25	$\frac{3}{\sqrt{n}}$	$\frac{3}{\sqrt{n}}$	.....	.....	.....	*	**	*	**	.....	.....	.....	.....	.....	.....	.....

$* \; 1 - \frac{3}{\sqrt{2n}}$ $\qquad$ $** \; 1 + \frac{3}{\sqrt{2n}}$

* Reproduced by permission from *ASTM Manual on Quality Control of Materials*, American Society for Testing Materials, Philadelphia, Pa., 1951.

An estimate of σ' is then $\bar{\sigma}/c_2$, where values of c_2 for different n can be found in Table 13.4.

To summarize, the estimated central line for the control chart for $\bar{x}$ is $\bar{\bar{x}}$, and the estimated control limits are $\bar{\bar{x}} \pm 3\bar{\sigma}/\sqrt{n}\, c_2$. Values of $3/(\sqrt{n}\, c_2) = A_1$

TABLE 13.5 FORMULAS FOR CENTRAL LINES AND CONTROL LIMITS

Statistic	Standards given		Analysis of past data	
	Central line	Limits	Central line	Limits
Average, using σ'	$\bar{x}'$	$\bar{x}' \pm A\sigma'$	$\bar{\bar{x}}$	$\bar{\bar{x}} \pm A_1\bar{\sigma}$
Average, using R	—	—	$\bar{\bar{x}}$	$\bar{\bar{x}} \pm A_2\bar{R}$
Standard deviation	$c_2\sigma'$	$B_1\sigma'$, $B_2\sigma'$	$\bar{\sigma}$	$B_3\bar{\sigma}$, $B_4\bar{\sigma}$
Range	$d_2\sigma'$	$D_1\sigma'$, $D_2\sigma'$	$\bar{R}$	$D_3\bar{R}$, $D_4\bar{R}$

can be found in Table 13.4 so that the estimated control limits can be written as $\bar{\bar{x}} \pm A_1\bar{\sigma}$.

2.3.4 Estimate of σ' by $\bar{R}$. Define, as the range (R) of a subgroup of n observations, the difference between the largest and smallest value. Let $\bar{R}$ be the average of the ranges of the k subgroups, i.e.,

$$\bar{R} = \frac{R_1 + R_2 + \ldots + R_k}{k}$$

Another estimate of σ' is $\bar{R}/d_2$. Values of d_2 for different values of n can be found in Table 13.4.

In estimating the control limits for $\bar{x}$ with $\bar{R}$ as an estimate of σ' the limits become $\bar{\bar{x}} \pm 3\bar{R}/\sqrt{n}\, d_2$. Values of $3/(\sqrt{n}\, d_2) = A_2$ can be found in Table 13.4, so that the estimated control limits can be written as $\bar{\bar{x}} \pm A_2\bar{R}$.

It must be pointed out that although $\bar{R}$ is simpler to calculate than $\bar{\sigma}$, the estimate of σ' based upon $\bar{\sigma}$ is a better estimate in the sense that on the average $\bar{\sigma}/c_2$ will lie nearer to σ' than $\bar{R}/d_2$ will.

2.3.5 Starting a control chart for $\bar{x}$. It has been pointed out that observations should be classified into rational subgroups, and each subgroup should contain at least 4 observations. The determination of the minimum number of subgroups is a compromise between obtaining the guidance of the control chart as quickly as possible, and the desire for the guidance to be reliable. Usually, at least 25 subgroups should be chosen.

With the data at hand, trial control limits can be calculated. Estimates of $\bar{x}'$ and σ' can be obtained in the manner described previously. The trial control limits are then $\bar{\bar{x}} \pm A_1\bar{\sigma}$ or $\bar{\bar{x}} \pm A_2\bar{R}$, depending upon which estimate of σ' is chosen. If σ' and/or $\bar{x}'$ are known, the control limits should be calculated, using the known values, e.g., if both are known, $\bar{x}' \pm 3\sigma'/\sqrt{n}$. Values of $3/\sqrt{n}$ can be found in Table 13.4, so that the control limits can be written $\bar{x}' \pm A\sigma'$.

Returning to the case where the parameters $\bar{x}'$ and σ' are unknown, and estimates have to be computed, some modifications may have to be made. Lack of control is usually indicated by points falling outside the limits. If all the points fall within the limits, the process is said to be in control. However, there is no assurance that assignable causes of variation are not present, and that this is a constant cause system. It merely means that for practical purposes it pays to act as if no assignable causes of variation are present, although realizing that an error of judgment is quite possible.

The trial control limits serve the purpose of determining whether past operations are in control. To continue using these limits as a basis for action on future production may require a revision of the trial limits, especially if a lack of control is exhibited by points falling outside the trial control limits. If the process is not in control, all the points do not come from a stable population. However, it is evident that future control limits should be based upon data from a controlled process. As a practical rule, then, those points falling outside the trial control limits are eliminated, and new trial control limits are computed using the remaining points. This procedure may be continued until all points fall within the control limits. There is no theoretical justification for this, other than the fact that those points falling outside the trial control limits are more likely to belong to another population, i.e., may be due to some assignable cause.

The control chart when used as a basis for action on future production may be set, using aimed-at values of $\bar{x}'$ and/or σ'. In this case, the control limits are modified by using the aimed-at values as if they were the known values in the computations. If this is done, and the control chart exhibits a lack of control in the future, the trouble may be that the process is not in control at the aimed-at values, but is in control at some other values. For example, suppose that an item is being produced at a level such that the mean $\bar{x}'$ is equal to 20. If the aimed-at value is $\bar{x}' = 25$, the control chart based on $\bar{x}' = 25$ will exhibit a lack of control. Suppose the mean can be shifted by a change in machine setting. The interpretation, then, is that there is an assignable cause present, namely, the machine setting, preventing the production process from operating at the aimed-at value. Yet, with the actual machine setting, the process is in control at $\bar{x}' = 20$. The term "state of control" may have to be interpreted in the above light. Aimed-at values of $\bar{x}'$ or σ' are often used when they can be achieved by a simple adjustment of the machine.

2.3.6 Relation between control limits and specification limits. After ascertaining at what level the process is in control by means of the control chart, it remains to determine whether or not the process can meet the specification limits set for the item. In Arts. 2.3.3 and 2.3.4, it was shown that σ' can be estimated from $\bar{\sigma}$ or $\bar{R}$, i.e., estimate of $\sigma' = \bar{\sigma}/c_2$ or $\bar{R}/d_2$. Furthermore, $\bar{x}'$ can be estimated from $\bar{\bar{x}}$. Consequently, it is known that if $\bar{x}'$ and σ' are really equal to the estimates, almost all the individual items will lie between $\bar{x}' \pm 3\sigma'$, i.e., on the average 9973 out of 10,000.

Specification limits are usually specified by giving an aimed-at value plus

an interval surrounding this value. These specification limits *should not* be interpreted as meaning that all the items produced will fall within these limits; but rather *almost* all. If the designer is pressed, he will admit to allowing, say 1 in 1000, to fall outside. Once the number is ascertained, the corresponding probability limits can be obtained from the estimated $\bar{x}'$ and σ'.★ For example, suppose the designer specifies specification limits of 20 ± 2, and he states that only 1 in 1000 should fall outside these limits. If the estimate of $\bar{x}'$ is 20.40 and $\sigma' = 1$, from the normal tables it follows that on that average, 999 out of 1000 items will fall between

$$[\bar{x}' - 3.29\sigma', \bar{x}' + 3.29\sigma'] = [17.11, 23.69]$$

The specification limits allow only [18, 22]. Consequently, the above process cannot meet the specification limits, and either the process must be changed or the specifications revised. To summarize, the specification limits must first be properly interpreted. As a practical rule, they are often interpreted to mean the allowance of 27 in 10,000 to fall outside. This corresponds to $3\sigma'$ limits. Then $\bar{x}' \pm 3\sigma'$★ is calculated and compared with the specification limits. If the specifications fall outside the probability limits, either the process must be altered, or the specifications revised.

2.3.7 **Interpretation of control charts for $\bar{x}$.** As long as the process is in control, almost all the values of $\bar{x}$ will fall within the control limits. In this case, no action need be taken. A point falling outside these limits is a signal to hunt for trouble. In some instances, production may be stopped until a source of trouble has been discovered. Occasionally, approximately 27 in 10,000 times, an error will be made in that trouble will be sought even though nothing has gone wrong with the process. On the other hand, if something has gone wrong with the process, points will begin to fall outside the control limits. For example, a shift in the mean $\bar{x}'$ (σ' remaining constant) will result in points falling outside the control limits. This is usually indicated by points falling above *or* below the limits (but never both), depending on whether the shift is in the positive or negative direction. On the other hand, an increase in σ' ($\bar{x}'$ remaining constant) will result in points falling above *and* below the control limits. In addition to examining the process, when points fall outside the control limits, the control limits themselves should be re-examined, and perhaps brought up to date.

It has been pointed out that an error may be committed when action is taken after a point falls outside the control limits. There is a small probability that a point will fall outside the control limits even though the process is in control, i.e., if $3\sigma'_{\bar{x}}$ limits are used the probability is 0.0027. This probability of falling outside the control limits when the process is in control is known as the probability of committing an *error of the first type* or *type 1 error*. Similarly, if the process goes out of control, there is a probability greater than 0, that a point will fall within the control limits. This is known as the probability of an *error of the second type* or *type 2 error*. These two errors are related. A decrease in one results in an increase in the other. An increase in one results in

★ Assuming the estimated values of $\bar{x}'$ and σ' are equal to $\bar{x}'$ and σ', respectively.

a decrease in the other. The use of $3\sigma'_{\bar{x}}$ limits implies a probability of a type 1 error of 0.0027. If the process jumps out of control, and the new level is specified, the probability of a type 2 error can be computed. If $2\sigma'_{\bar{x}}$ limits were used instead of $3\sigma'_{\bar{x}}$, the probability of a type 1 error is increased to about 0.0455, but the probability of a type 2 error is decreased.

2.3.8 **Example.** Suppose $\bar{x}'$ is 25, and $\sigma' = 1$, and there are 4 observations in each subgroup. The control limits are then $25 \pm \frac{3}{2}$. The probability of a type 1 error is 0.0027. If the mean shifts to 27, the probability of a point falling inside the control limits of $25 \pm \frac{3}{2}$ is 0.1587. On the other hand, if $2\sigma'_{\bar{x}}$ is used as control limits (25 ± 1) the probability of a type 1 error is increased to 0.0455, whereas the probability of committing a type 2 error is only 0.0228.

It is evident that type 1 errors or type 2 errors (but not both) can be made as small as is desirable, at the expense of increasing the other type error. It is also evident that using $3\sigma'_{\bar{x}}$ limits is conservative from the point of view of considering the type 1 error. A point falling outside the control limits is almost sure evidence that the process is no longer in control. On the other hand, one cannot be assured that a small shift has not taken place even if the points fall within the control limits.

2.4 *R* CHARTS AND σ CHARTS

2.4.1 **Statistical concepts.** Although both R and σ *do not* have normal distributions, both of these functions are chance variables, each having a distribution. Furthermore, the population mean (of these chance variables) plus and minus three standard deviations (of these variables) contain almost all of the underlying population. Consequently, for control chart purposes, it is necessary to calculate both the population mean value and standard deviation of these chance variables.

The population average of σ is $c_2\sigma'$. The standard deviation of σ is

$$\sigma_\sigma = [2(n-1) - 2nc_2^2]^{1/2} \frac{\sigma'}{\sqrt{2n}}$$

The control limits are then $c_2\sigma' \pm 3\sigma_\sigma$ which can be written

$$\sigma'\left(c_2 \pm \frac{3}{\sqrt{2n}}[2(n-1) - 2nc_2^2]^{1/2}\right)$$

The factors

$$B_2 = c_2 + \frac{3}{\sqrt{2n}}[2(n-1) - 2nc_2^2]^{1/2}$$

$$B_1 = c_2 - \frac{3}{\sqrt{2n}}[2(n-1) - 2nc_2^2]^{1/2}$$

can be obtained from Table 13.4. Thus

$$UCL_\sigma = B_2\sigma'; \qquad LCL_\sigma = B_1\sigma'$$

When σ' is unknown, it can be estimated from $\bar{\sigma}/C_2$, so that the estimated control limits are written

$$\bar{\sigma}\left\{1 \pm \frac{3}{\sqrt{2n}\, c_2}\,[2(n-1) - 2nc_2^2]^{1/2}\right\}$$

The factors

$$B_4 = 1 + \frac{3}{\sqrt{2n}\, c_2}\,[2(n-1) - 2nc_2^2]^{1/2}$$

$$B_3 = 1 - \frac{3}{\sqrt{2n}\, c_2}\,[2(n-1) - 2nc_2^2]^{1/2}$$

can be obtained from Table 13.4. The estimated control limits are then

$$UCL_\sigma = B_4\bar{\sigma}; \qquad LCL_\sigma = B_3\bar{\sigma}$$

Note that the center line is $c_2\sigma'$ if σ' is known, and $\bar{\sigma}$ if σ' is unknown.

The control limits for R are obtained in a similar manner. The population average of R is $d_2\sigma'$. The standard deviation of R is $\sigma_R = d_3\sigma'$. The control limits are then $d_2\sigma' \pm 3\sigma_R$, which can be written $\sigma'\ (d_2 \pm 3d_3)$. The factors

$$D_2 = d_2 + 3d_3; \qquad D_1 = d_2 - 3d_3$$

can be obtained from Table 13.4. Thus

$$UCL_R = D_2\sigma'; \qquad LCL_R = D_1\sigma'$$

When σ' is unknown, it can be estimated from $\bar{R}/d_2$ so that the estimated control limits are written

$$\bar{R}\left[1 \pm 3\frac{d_3}{d_2}\right]$$

The factors

$$D_4 = 1 + 3\frac{d_3}{d_2}; \qquad D_3 = 1 - 3\frac{d_3}{d_2}$$

can be obtained from Table 13.4. The estimated control limits are then

$$UCL_R = D_4\bar{R}; \qquad LCL_R = D_3\bar{R}$$

The center line is $d_2\sigma'$ if σ' is known, and $\bar{R}$ if σ' is unknown.

2.4.2 Setting up a control chart for R or σ. The range of each subgroup should be obtained and $\bar{R}$ calculated from these values. The control limits are obtained from

$$UCL_R = D_4\bar{R}; \qquad LCL_R = D_3\bar{R}$$

If a σ chart is desired, similar calculations are made in accordance with the rules described above. If all the points fall inside the control limits, no modification is made unless it is desired to reduce the process dispersion. In this case, an aimed-at value of σ' should be used in the calculations. When the $\bar{R}$ (or σ) chart indicates a possible lack of control by points falling outside the control limits, it is desirable to estimate the value of σ' that might be attained if the dispersion were brought into control. A method of estimation is to eliminate those points out of control (only those above the UCL_R if points

fall both above and below) and recompute the values of the control limits based only on the remaining observations. If more points fall out of control, the procedure is carried out once again.

The final revised values of $\bar{R}$, $\bar{\sigma}$, or σ', whichever is used, may also be used to obtain new control limits for $\bar{x}$. This has the effect of tightening the limits on the $\bar{x}$ chart, making them consistent with a σ' that may be estimated from the revised $\bar{R}$ or $\bar{\sigma}$.

Control limits should be revised from time to time as additional data are accumulated.

2.5 EXAMPLE OF $\bar{x}$ AND R CHART

The following are the $\bar{x}$ and R values for 20 subgroups of five readings.

The specifications for this product characteristic are 0.4037 ± 0.0010. The values given are the last two figures of the dimension reading, i.e., 31.6 should be 0.40316.

group	$\bar{x}$	R	Subgroup	$\bar{x}$	R	group	$\bar{x}$	R
1	34.0	4	8	32.6	13	15	33.8	7
2	31.6	4	9	33.8	19	16	31.6	5
3	30.8	2	10	37.8	6	17	33.0	5
4	33.0	3	11	35.8	4	18	28.2	3
5	35.0	5	12	38.4	4	19	31.8	9
6	32.2	2	13	34.0	14	20	35.6	6
7	33.0	5	14	35.0	4			

$\sum \bar{x} = 671.0,\ \bar{\bar{x}} = 33.6;\ \sum R = 124,\ \bar{R} = 6.20$

The trial control limits are computed from

$$\bar{\bar{x}} \pm A_2\bar{R}; \qquad UCL_{\bar{x}} = 37.2; \qquad UCL_R = (2.115)(6.20) = 13.1$$

$$\bar{\bar{x}} \pm (0.577)(6.20); \qquad LCL_{\bar{x}} = 30.0; \qquad LCL_R = 0$$

$$\bar{\bar{x}} \pm 3.58$$

The control charts for $\bar{x}$ and R with trial limits are shown in Fig. 13.7. Since some points fall outside the control limits, the process is assumed to be out of control. Eliminating these points, new control limits are computed.

$$\sum \bar{x} = 5660; \qquad \bar{\bar{x}} = 33.3$$

$$\sum R = 91; \qquad \bar{R} = 5.06$$

$$UCL_{\bar{x}} = 33.3 + (0.577)(5.06) = 33.3 + 2.92 = 36.2$$

$$LCL_{\bar{x}} = 33.3 - (0.577)(5.06) = 33.3 - 2.92 = 30.4$$

$$UCL_R = (2.115)(5.06) = 10.7; \qquad LCL_R = (2.115)(0) = 0$$

None of the remaining points fall outside the limits. If it is now assumed that the process can be brought into control at this level we find $\bar{x}' = 33.3$ and $\sigma' = 2.175$. The value of σ' is obtained from

$$d_2 = \bar{R}/\sigma'; \qquad \sigma' = \bar{R}/d_2 = 5.06/2.326 = 2.175$$

$$[\bar{x}' - 3\sigma'\ \ \bar{x}' + 3\sigma'] = [\bar{x}' - 6.525, \bar{x}' + 6.525] = [26.8, 39.8]$$

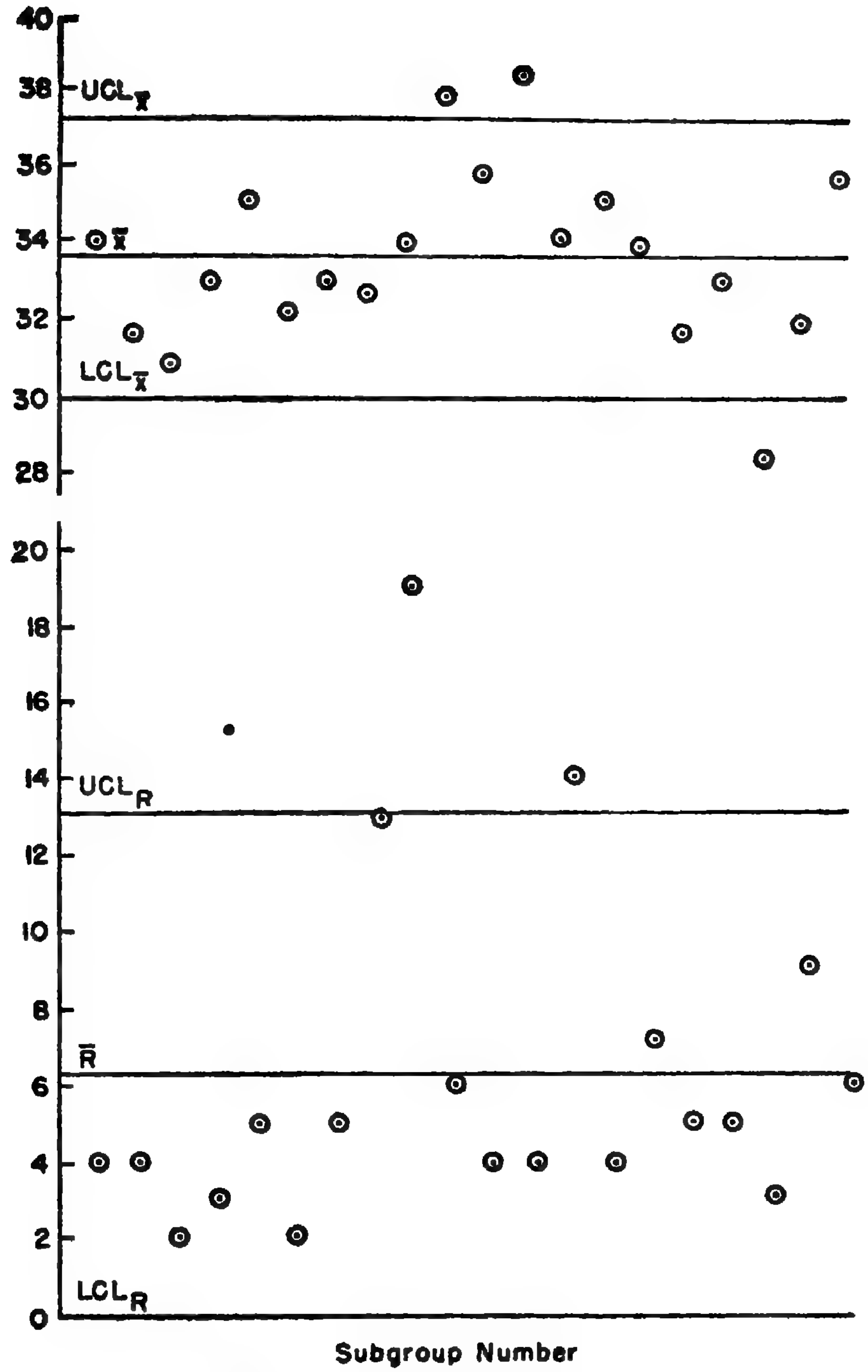


FIG. 13.7 CONTROL CHART FOR $\bar{x}$ AND R.

In terms of the actual data, $[\bar{x}' - 3\sigma', \bar{x}' + 3\sigma'] = [0.4027, 0.4040]$. The specifications are

$$[0.4037 - 0.0010, 0.4037 + 0.0010] = [0.4027, 0.4047]$$

so that this production process is able to meet these specifications even though the process is not centered at the nominal value of 0.4037 provided the process remains in control at the above level.

2.6 CONTROL CHART FOR FRACTION DEFECTIVE

2.6.1 Relation between control charts based on variables data and charts based on attribute data. The $\bar{x}$ and R control charts are charts for variables, i.e., for quality characteristics that can be measured and expressed in numbers. However, many quality characteristics can be observed only as attributes, i.e., by classifying the item into one of two classes, usually defective or nondefective. Furthermore, with the existing techniques, an $\bar{x}$ and R chart can be used for only one measurable characteristic at a time. For example, if an item consists of 10,000 measurable characteristics, each characteristic is a candidate for an $\bar{x}$ and R chart. However, it would be impossible to have 10,000 such charts, and only the most important and troublesome would be charted. As an alternative to $\bar{x}$ and R charts, and as a substitute when characteristics are measured only by attributes, a control chart based on the fraction defective can be used. This is known as a p chart. A p chart can be applied to quality characteristics that are actually observed as attributes even though they may have been measured as variables. The cost of obtaining attribute data is usually less than that for obtaining variables data. The cost of computing and charting may also be less, since one p chart can apply to any number of characteristics.

Basically, the p chart has the same objective as an $\bar{x}$ and R chart. It discloses the presence of assignable causes of variation, although it is not so sensitive as an $\bar{x}$ and R chart.

2.6.2 Statistical theory. The statistical theory of the binomial distribution discussed in Art. 1.3 is applicable here. Let the probability of an item being defective be given by p', so that the probability of obtaining exactly d defectives in a sample of n is $\binom{n}{d}p'^d(1-p')^{n-d}$. The probability of obtaining a defectives or less in a sample of n is

$$\sum_{d=0}^{a}\binom{n}{d}p'^d(1-p')^{n-d} = \binom{n}{0}p'^0(1-p')^n + \binom{n}{1}p'^1(1-p')^{n-1} + \dots + \binom{n}{a}p'^a(1-p')^{n-a}$$

Furthermore, the mean value of the total number of defectives in a sample of n is np', and the standard deviation is $\sqrt{np'(1-p')}$.

If the fraction defective p is defined as the ratio of the number of defectives d to the total number of items in the sample n—i.e., d/n—the mean value of the fraction defective is p' and the standard deviation is $\sqrt{p'(1-p')/n}$.

As a working rule, the control limits for the fraction defective are defined as

$$UCL_p = p' + 3\sqrt{\frac{p'(1-p')}{n}}; \qquad LCL_p = p' - 3\sqrt{\frac{p'(1-p')}{n}}$$

It is important to note that the probability of d/n falling within these limits depends on the value of p', even if the process is in control.* However, almost

* This is quite different from the $\bar{x}$ chart, where the probability of $\bar{x}$ falling between $\bar{x}' \pm 3\sigma'/\sqrt{n}$ is 0.9973 for any values of $\bar{x}'$ and σ' provided the process is in control.

all the d/n will fall within the above limits provided the process is in control. Furthermore, the above limits result in a simple empirical rule and for large n, result in an accurate approximation.

If p' is not known, it is usually estimated from past data. The rules are similar to those used in estimating the parameters for the $\bar{x}$ charts. The estimate in this case is d_T/n_T where d_T is the total number of defectives found in the past data of size n_T.

It often happens in control charts for fraction defective that the size of the subgroup varies. In this case, three possible solutions to the problem are as follows: (1) Compute control limits for every subgroup and show these fluctuating limits on the p chart. (2) Estimate the average subgroup size, and compute one set of limits for this average and draw them on the control chart. This method is approximate and is appropriate only when the subgroup sizes are not too variable. Points near the limits may have tobe re-examined in accordance with (1). (3) Draw several sets of control limits on the chart corresponding to different subgroup sizes. This method is also approximate and is actually a cross between (1) and (2). Again, points falling near the limits should be re-examined in accordance with (1).

2.6.3 Starting the control chart. The subgroup size is usually large compared with that used for $\bar{x}$ and R charts. The main reason for this is that if p' is very small, and n is small, the expected number of defectives in a subgroup will be very close to 0.

For each subgroup compute p, where

$$p = \frac{\text{number of defectives in the subgroup}}{\text{number inspected in the subgroup}}$$

Whenever practicable, no fewer than 25 subgroups should be used to compute trial control limits. These limits are computed from the data by finding the average fraction defective $\bar{p}$, where

$$\bar{p} = \frac{\text{total number of defectives during period}}{\text{total number inspected during period}}$$

and substituting in the relations

$$UCL_p = \bar{p} + \frac{3\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}}; \qquad LCL_p = \bar{p} - \frac{3\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}}$$

Inferences about the existence of control or lack of control can be drawn in a manner similar to that described for the $\bar{x}$ and R chart.

2.6.4 Continuing the p chart. The preliminary plot reveals two facts, namely, whether or not the process is in an apparent state of control, and the quality level. If the process appears to be in control, it may be in control at too high a level, i.e., the estimate of p' is higher than can be tolerated. In this case, the production process must be examined, and possible major changes made. On the other hand, the estimate of p' may indicate a good quality level even though the process may appear to be out of control. In this case assignable causes should be sought and eliminated. Of course, control limits can be

determined on the basis of an aimed-at value of p', but an indicated lack of control must be interpreted with this in mind.

At first glance, points falling below the lower control limit may appear to be desirable. However, this may be attributed to a poor estimate of p', although it may possibly indicate a change for the better in the quality level; and tracking down the assignable cause may enable an improvement to be made in the production process. In either case, points falling below the lower control limit call for a re-examination of the control chart or the production process or both.

2.6.5 **Example.** A sample of 50 pieces is drawn from the production of the last two hours from a single spindle automatic screw machine and each item is checked by go and no-go gauges for several possible sources of defectives. The number of defective items found in 25 such successive samples were:

Subgroup	d	p	Subgroup	d	p	Subgroup	d	p
1	1	0.02	9	1	0.02	18	0	0.00
2	2	.04	10	0	.00	19	0	.00
3	5	.10	11	0	.00	20	1	.02
4	6	.12	12	1	.02	21	1	.02
5	3	.06	13	0	.00	22	0	.00
6	5	.10	14	1	.02	23	0	.00
7	2	.04	15	0	.00	24	1	.02
8	1	.02	16	2	.04	25	0	.00
			17	1	.02			

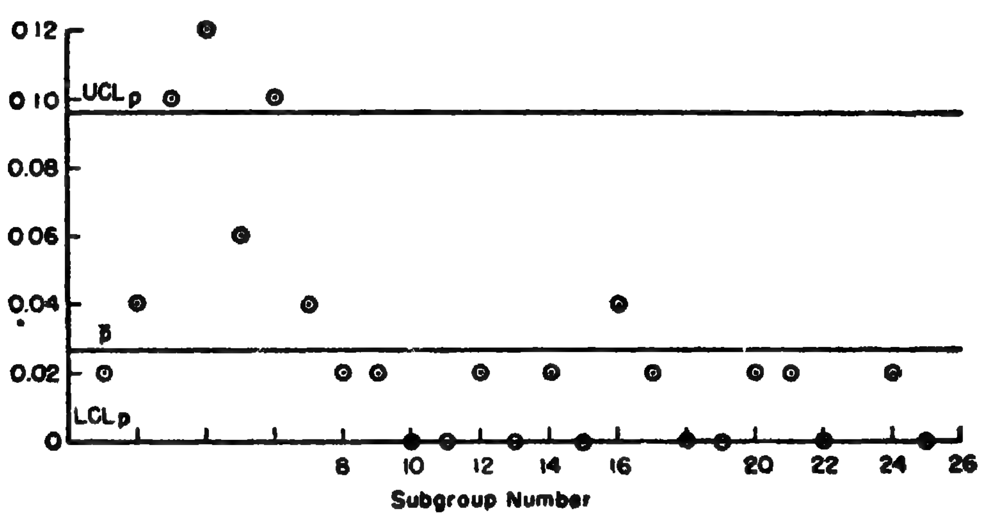
$$\bar{p} = \frac{34}{1250} = 0.0272$$

$$UCL = 0.0272 + \frac{3\sqrt{(0.0272)(0.9728)}}{7.071} = 0.0963$$

$$LCL = 0$$

The control chart for p with trial limits is shown in Fig. 13.8. Many points fall outside the control limits, and it appears that an assignable cause of variation was present when the first samples were taken that was not present when

FIG. **13.8** CONTROL CHART FOR p.



the later samples were taken. Recomputing the control limits starting with the seventh sample we find

$$\bar{p} = \frac{12}{950} = 0.0126$$

$$UCL = 0.0126 + \frac{3\sqrt{(0.0126)(0.9874)}}{7.071} = 0.0599$$

$$LCL = 0$$

No points fall outside these limits and hence we use these as the control limits for future production.

2.7 CONTROL CHARTS FOR DEFECTS

2.7.1 Difference between a defect and a defective. An item is considered to be defective if it fails to conform to the specifications in any of the characteristics. Each characteristic that does not meet the specifications is a defect. An item is defective if it contains at least one defect.

The c chart is a control chart for defects per unit. The unit considered may be a single item, a group of items, part of an item, etc. The unit is examined and the number of defects found is recorded on the c chart. If, for each unit, there are numerous opportunities for defects to occur, and if the probability of a defect occurring in a particular spot is small, the statistical theory for the c chart is based on the Poisson distribution. Some examples where c charts are applicable are in counting the number of defective rivets on an airplane wing, the number of imperfections in a piece of cloth, etc.

2.7.2 Statistical theory. The probability of finding c defects in an item where the number of defects follows the Poisson law is $c'^{c}e^{-c'}/c!$, where c' is the *average* number of defects per unit, and the standard deviation is $\sqrt{c'}$.

As a working rule, control limits for the c chart are defined as

$$UCL_c = c' + 3\sqrt{c'}; \qquad LCL_c = c' - 3\sqrt{c'}$$

As in the case of the control chart for the fraction defective, these limits do not guarantee that a fixed percentage of the population will lie between them for all values of c' even if the process is in control, i.e., the probability of c falling between these limits depends on the value of c'. However, for practical purposes, it can be assumed that "almost all the values" will fall between the control limits provided the process is in control.

If c' is not known, it is usually estimated from past data. The rules are similar to those used in estimating the parameters from the $\bar{x}$ charts. The estimate in this case is $\bar{c} = c_T/N_T$ where c_T is the total number of defects found in N_T units.

2.7.3 Starting and continuing the control. The discussion on starting and continuing the control chart for fraction defective given in Arts. 2.6.3 and 2.6.4 is pertinent to the c chart.

2.7.4 Example. The following table gives the number of missing rivets noted

at final inspection on 25 airplanes. Read column downward and from left to right.

8	15	23	9	10
16	8	16	9	22
14	11	9	14	7
19	21	25	11	28
11	12	15	9	9

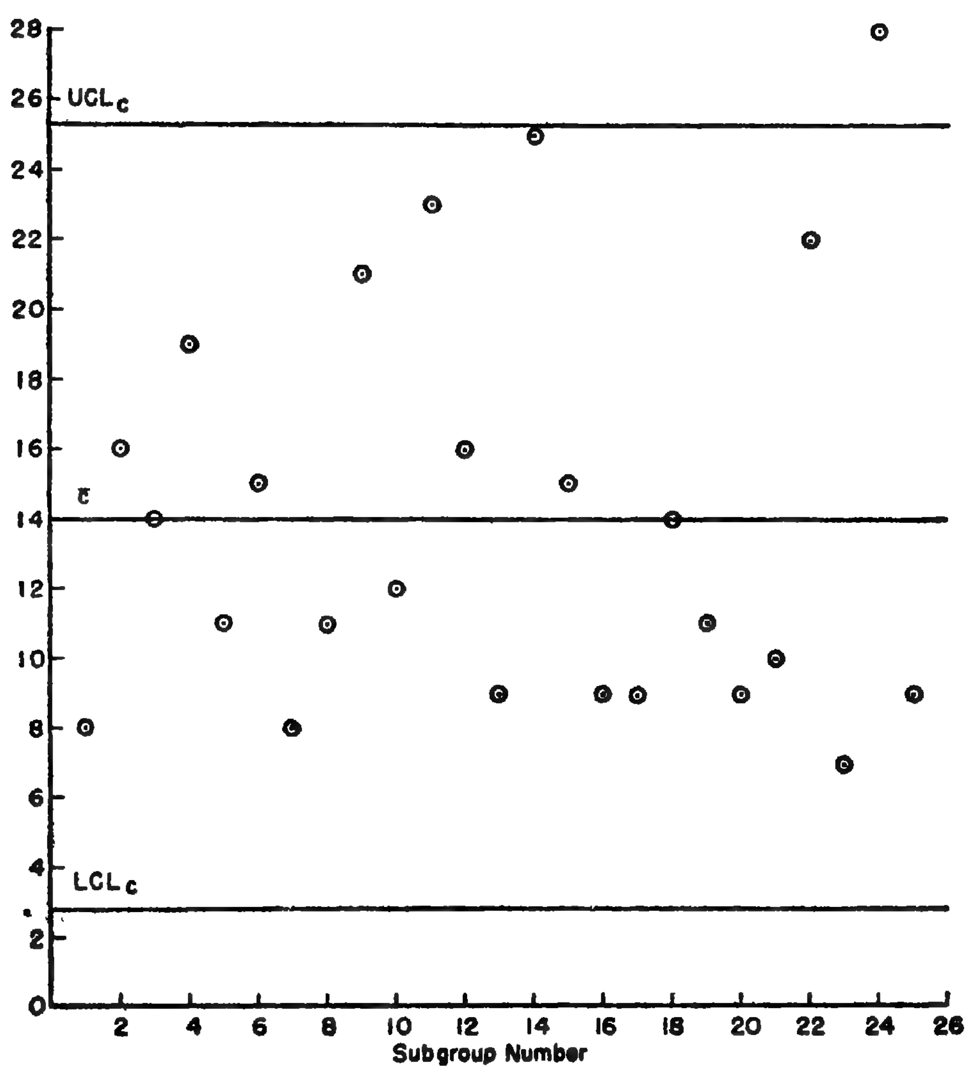
$$\bar{c} = \frac{351}{25} = 14.04$$

$$UCL_c = 14.04 + 3\sqrt{14.04} = 25.26$$

$$LCL_c = 14.04 - 3\sqrt{14.04} = 2.82$$

The control chart for c with trial limits is shown in Fig. 13.9. However, the next to the last plane falls outside the control limits, and it would be best to base future calculations on a $\bar{c}$ which did not involve this airplane.

FIG. 13.9 CONTROL CHART FOR c.



$$\bar{c} = \frac{323}{24} = 13.46$$

$$UCL_c = 13.46 + 3\sqrt{13.46} = 24.47$$

$$LCL_c = 13.46 - 3\sqrt{13.46} = 2.45$$

The fourteenth airplane now falls outside the control limits, so that $\bar{c}$ is again recomputed without the results for this plane.

$$\bar{c} = \frac{298}{23} = 12.96$$

$$UCL_c = 12.96 + 3\sqrt{12.96} = 23.76$$

$$LCL_c = 12.96 - 3\sqrt{12.96} = 2.16$$

3. SAMPLING INSPECTION

3.1 INTRODUCTION

Sampling inspection is of two kinds, namely, lot-by-lot sampling inspection and continuous sampling inspection. In the former, items are formed into lots, a sample is drawn from the lot, and the lot is either accepted or rejected on the basis of the quality of the sample. This is most appropriate for acceptance inspection. In continuous sampling inspection, current inspection results are used to determine whether sampling inspection or screening inspection is to be used for the next articles to be inspected. Sampling plans are further classified depending on whether the quality characteristics are measured and expressed in numbers, i.e., variables inspection; or whether articles are classified only as defective or nondefective, i.e., attributes inspection.

An alternative to sampling inspection is to screen every item. The cost of such a scheme is prohibitive, with perfect quality rarely achieved. Still another advantage of sampling inspection schemes—if properly designed—is that they create more effective pressure for quality improvement, and therefore result in the submission of better quality product for inspection.

Although the above factors were recognized somewhat prior to World War II, and a few sampling inspection schemes were then in use, it wasn't until the outbreak of hostilities that modern sampling inspection received its impetus. Good sampling plans replaced bad ones, sometimes at the expense of an increase in the total amount of inspection but almost always resulting indirectly in better quality being produced.

Any lot-by-lot sampling plan has as its primary purpose the acceptance of good lots and the rejection of bad lots. It is important to define what is meant by a good lot. Naturally, the consumer would like all of his accepted lots to be free of defectives. On the other hand, the manufacturer will usually consider this to be an unreasonable request since some defectives are bound to appear in the manufacturing process. If the manufacturer screens the lot

a few times he may get rid of all the defectives, but at the prohibitive cost of screening. This cost will naturally be reflected in his price to the consumer. Ordinarily, the consumer can really tolerate some defectives in his lot, provided the number is not too large. Consequently, the manufacturer and the consumer get together and agree on what constitutes good quality. If lots are submitted at this quality or better, the lot should be accepted, otherwise, rejected. Again this is an imposing task and can be accomplished only at the expense of screening. It is at this point that sampling inspection, with its corresponding advantage of reduced inspection costs, can be instituted. This advantage should not be minimized. Few manufacturers or consumers, whichever has to bear the cost of inspection, can stay in business very long if all lots are screened.

3.2 DRAWING THE SAMPLE

A decision must be made on what shall constitute a lot for acceptance purposes, for each lot must be identified. Each lot should represent, as nearly as possible, the output of one machine or process during one interval of time, so that all parts or products in the lot have been turned out under essentially the same conditions. Wherever practicable, parts from different sources or different conditions should not be mixed into one lot. The power of the sampling plans to distinguish between good and bad lots is dependent on the variation from lot to lot, and provision should be made to maintain the identity of, and prevent the mixing of, the different lots.

A sample from each lot supplies the information on which the decision to accept or reject the lot is based. Therefore it is essential that the sample be drawn from each lot in a random manner. A sample is random if every piece in the lot has an equal chance of being selected. This may be accomplished by using a table of random numbers, a deck of cards, or some such chance method, to insure the equal chance for each piece. Human attempts to randomize a sample without such aids often result in biased samples.

3.3 LOT-BY-LOT SAMPLING INSPECTION BY ATTRIBUTES: SINGLE SAMPLING

A single sampling procedure can be characterized by the following: One sample of n items is drawn from a lot of N items; the lot is accepted if the number of defectives d in the sample does not exceed c. Here c is referred to as the acceptance number.

Certain risks must be taken if sampling inspection is to be used. A graph of these risks plotted as a function of the incoming lot quality (p') is known as an operating characteristic (OC) curve.

If quality is good, it is desirable to have the probability of acceptance high. On the other hand, if quality is bad, it is desirable to have the probability of acceptance small. Note that if p' is 0, the lot contains no defectives and hence the lot will always be accepted, i.e., $L(p') = 1$. If p' is 1 the entire

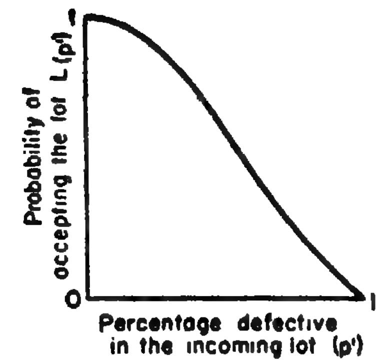


FIG. 13.10 OPERATING CHARACTERISTIC CURVE.

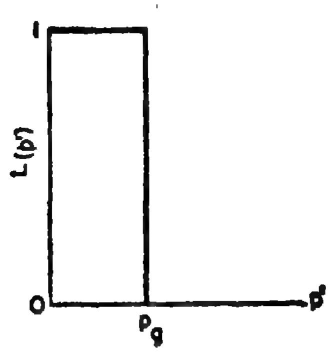
lot is defective and hence the sample will always contain all defectives so that the lot will always be rejected, i.e., $L(p') = 0$.

Assume that a quality standard p_g is established and that all lots better than this standard are considered to be "good" and all lots worse are considered to be "bad." An "ideal" OC curve would then be of the form shown in Fig. 13.11, with all good lots accepted and all bad ones rejected. Obviously, no sampling plan can have such a curve. The degree of approximation to the ideal curve depends on n and c.

If c is held constant, and n is increased, the slope becomes steeper. On the other hand, holding n constant and changing the acceptance number has the effect of shifting the OC curve to the left or right.

If the lot size N is large compared with the sample size n, the OC curve is essentially independent of the lot size. In other words, if the OC curve of a sampling plan defined by a sample of size n, a lot of size N, and an acceptance number of c is compared with the OC curve of a sampling plan defined by a sample of size n, a lot of size $N_1 (N_1 > N)$, and an acceptance number of c, the difference is negligible, if the sample size is small compared with the lot size. Since this is the situation in most industrial applications, we will make this assumption throughout the rest of this section. As a result, a single sampling plan will now be defined by only two numbers, the sample size n and acceptance number c.*

FIG. 13.11 IDEAL OPERATING CHARACTERISTICS CURVE.



* From a mathematical viewpoint, this implies that the binomial distribution can be used as an approximation to the hypergeometric distribution.

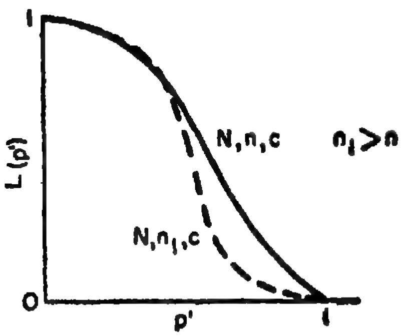


FIG. 13.12 EFFECT ON OC OF VARING n.

The single sampling procedure can be viewed from another side. By drawing a sample of n, and looking at the number of defectives d present, the consumer is essentially estimating the percentage defective, i.e., $\hat{p} = d/n$ is an estimate of the incoming quality p'. A lot is rejected if this estimate is too high, i.e., if $\hat{p} > c/n = p^*$. Therefore, a procedure which says to reject a lot if the number of defectives d is greater than c in a sample of size n is equivalent to rejecting a lot if the estimated percentage defective, $d/n = \hat{p}$, is greater than $c/n = p^*$. This viewpoint will be useful later in the discussion of sampling inspection by variables.

3.3.1 **Choosing a sampling plan.** The consumer has at his disposal the choice of one of many OC curves. The one chosen should reflect his views as to the cost of making wrong decisions. By varying n and c, he can always find an OC curve which will pass through two preassigned points. In other words, by specifying the points $[p_1', L(p_1')]$ and $[p_2', L(p_2')]$, an n and a c can be found such that the OC curve passes through these two points. Before using sampling inspection, then, the consumer can locate two points p_1' and p_2' such that if quality is submitted better than p_1', he will accept the lot with probability greater than $L(p_1') = 1 - \alpha$; and if quality is submitted worse than p_2' he will accept the lot with probability less than $L(p_2') = \beta$. Here α is known as the producer's risk and β is known as the consumer's risk. The long-run average of submitted quality is known as the process average.

3.3.2 **Calculation of OC curves for single sampling plans.** It was pointed out previously that a sampling plan is defined by two numbers: n, the sample

FIG. 13.13 EFFECT ON OC OF VARYING c.

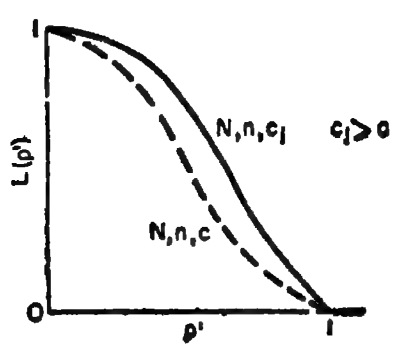


TABLE 13.6 SUMMATION OF TERMS OF POISSON'S EXPONENTIAL BINOMIAL LIMIT★

1,000 × probability of c or less occurrences of event that has average number of occurrences equal to c' or np'

c' or np' \ c	0	1	2	3	4	5	6	7	8	9
0.02	980	1,000								
0.04	961	999	1,000							
0.06	942	998	1,000							
0.08	923	997	1,000							
0.10	905	995	1,000							
0.15	861	990	999	1,000						
0.20	819	982	999	1,000						
0.25	779	974	998	1,000						
0.30	741	963	996	1,000						
0.35	705	951	994	1,000						
0.40	670	938	992	999	1,000					
0.45	638	925	989	999	1,000					
0.50	607	910	986	998	1,000					
0.55	577	894	982	998	1,000					
0.60	549	878	977	997	1,000					
0.65	522	861	972	996	999	1,000				
0.70	497	844	966	994	999	1,000				
0.75	472	827	959	993	999	1,000				
0.80	449	809	953	991	999	1,000				
0.85	427	791	945	989	998	1,000				
0.90	407	772	937	987	998	1,000				
0.95	387	754	929	984	997	1,000				
1.00	368	736	920	981	996	999	1,000			
1.1	333	699	900	974	995	999	1,000			
1.2	301	663	879	966	992	998	1,000			
1.3	273	627	857	957	989	998	1,000			
1.4	247	592	833	946	986	997	999	1,000		
1.5	223	558	809	934	981	996	999	1,000		
1.6	202	525	783	921	976	994	999	1,000		
1.7	183	493	757	907	970	992	998	1,000		
1.8	165	463	731	891	964	990	997	999	1,000	
1.9	150	434	704	875	956	987	997	999	1,000	
2.0	135	406	677	857	947	983	995	999	1,000	

★ Reprinted by permission from E. L. Grant, *Statistical Quality Control*, 2nd ed. (New York: McGraw-Hill Book Company, Inc., 1952).

TABLE 13.6 SUMMATION OF TERMS OF POISSON'S EXPONENTIAL BINOMIAL LIMIT (*Continued*)

c' or np' \ c	0	1	2	3	4	5	6	7	8	9
2.2	111	355	623	819	928	975	993	998	1,000	
2.4	091	308	570	779	904	964	988	997	999	1,000
2.6	074	267	518	736	877	951	983	995	999	1,000
2.8	061	231	469	692	848	935	976	992	998	999
3.0	050	199	423	647	815	916	966	988	996	999
3.2	041	171	380	603	781	895	955	983	994	998
3.4	033	147	340	558	744	871	942	977	992	997
3.6	027	126	303	515	706	844	927	969	988	996
3.8	022	107	269	473	668	816	909	960	984	994
4.0	018	092	238	433	629	785	889	949	979	992
4.2	015	078	210	395	590	753	867	936	972	989
4.4	012	066	185	359	551	720	844	921	964	985
4.6	010	056	163	326	513	686	818	905	955	980
4.8	008	048	143	294	476	651	791	887	944	975
5.0	007	040	125	265	440	616	762	867	932	968
5.2	006	034	109	238	406	581	732	845	918	960
5.4	005	029	095	213	373	546	702	822	903	951
5.6	004	024	082	191	342	512	670	797	886	941
5.8	003	021	072	170	313	478	638	771	867	929
6.0	002	017	062	151	285	446	606	744	847	916

	10	11	12	13	14	15	16
2.8	1,000						
3.0	1,000						
3.2	1,000						
3.4	999	1,000					
3.6	999	1,000					
3.8	998	999	1,000				
4.0	997	999	1,000				
4.2	996	999	1,000				
4.4	994	998	999	1,000			
4.6	992	997	999	1,000			
4.8	990	996	999	1,000			
5.0	986	995	998	999	1,000		
5.2	982	993	997	999	1,000		
5.4	977	990	996	999	1,000		
5.6	972	988	995	998	999	1,000	
5.8	965	984	993	997	999	1,000	
6.0	957	980	991	996	999	999	1,000

TABLE 13.6 SUMMATION OF TERMS OF POISSON'S EXPONENTIAL BINOMIAL LIMIT (*Continued*)

c′ or np′	0	1	2	3	4	5	6	7	8	9
6.2	002	015	054	134	259	414	574	716	826	902
6.4	002	012	046	119	235	384	542	687	803	886
6.6	001	010	040	105	213	355	511	658	780	869
6.8	001	009	034	093	192	327	480	628	755	850
7.0	001	007	030	082	173	301	450	599	729	830
7.2	001	006	025	072	156	276	420	569	703	810
7.4	001	005	022	063	140	253	392	539	676	788
7.6	001	004	019	055	125	231	365	510	648	765
7.8	000	004	016	048	112	210	338	481	620	741
8.0	000	003	014	042	100	191	313	453	593	717
8.5	000	002	009	030	074	150	256	386	523	653
9.0	000	001	006	021	055	116	207	324	456	587
9.5	000	001	004	015	040	089	165	269	392	522
10.0	000	000	003	010	029	067	130	220	333	458
	10	11	12	13	14	15	16	17	18	19
6.2	949	975	989	995	998	999	1,000			
6.4	939	969	986	994	997	999	1,000			
6.6	927	963	982	992	997	999	999	1,000		
6.8	915	955	978	990	996	998	999	1,000		
7.0	901	947	973	987	994	998	999	1,000		
7.2	887	937	967	984	993	997	999	999	1,000	
7.4	871	926	961	980	991	996	998	999	1,000	
7.6	854	915	954	976	989	995	998	999	1,000	
7.8	835	902	945	971	986	993	997	999	1,000	
8.0	816	888	936	966	983	992	996	998	999	1,000
8.5	763	849	909	949	973	986	993	997	999	999
9.0	706	803	876	926	959	978	989	995	998	999
9.5	645	752	836	898	940	967	982	991	996	998
10.0	583	697	792	864	917	951	973	986	993	997
	20	21	22							
8.5	1,000									
9.0	1,000									
9.5	999	1,000								
10.0	998	999	1,000							

TABLE 13.6 SUMMATION OF TERMS OF POISSON'S EXPONENTIAL BINOMIAL LIMIT (*Continued*)

c' or np' \ c	0	1	2	3	4	5	6	7	8	9
10.5	000	000	002	007	021	050	102	179	279	397
11.0	000	000	001	005	015	038	079	143	232	341
11.5	000	000	001	003	011	028	060	114	191	289
12.0	000	000	001	002	008	020	046	090	155	242
12.5	000	000	000	002	005	015	035	070	125	201
13.0	000	000	000	001	004	011	026	054	100	166
13.5	000	000	000	001	003	008	019	041	079	135
14.0	000	000	000	000	002	006	014	032	062	109
14.5	000	000	000	000	001	004	010	024	048	088
15.0	000	000	000	000	001	003	008	018	037	070
	10	11	12	13	14	15	16	17	18	19
10.5	521	639	742	825	888	932	960	978	988	994
11.0	460	579	689	781	854	907	944	968	982	991
11.5	402	520	633	733	815	878	924	954	974	986
12.0	347	462	576	682	772	844	899	937	963	979
12.5	297	406	519	628	725	806	869	916	948	969
13.0	252	353	463	573	675	764	835	890	930	957
13.5	211	304	409	518	623	718	798	861	908	942
14.0	176	260	358	464	570	669	756	827	883	923
14.5	145	220	311	413	518	619	711	790	853	901
15.0	118	185	268	363	466	568	664	749	819	875
	20	21	22	23	24	25	26	27	28	29
10.5	997	999	999	1,000						
11.0	995	998	999	1,000						
11.5	992	996	998	999	1,000					
12.0	988	994	997	999	999	1,000				
12.5	983	991	995	998	999	999	1,000			
13.0	975	986	992	996	998	999	1,000			
13.5	965	980	989	994	997	998	999	1,000		
14.0	952	971	983	991	995	997	999	999	1,000	
14.5	936	960	976	986	992	996	998	999	999	1,000
15.0	917	947	967	981	989	994	997	998	999	1,000

TABLE 13.6 SUMMATION OF TERMS OF POISSON'S EXPONENTIAL BINOMIAL LIMIT (*Continued*)

c' or np' \ c	4	5	6	7	8	9	10	11	12	13
16	000	001	004	010	022	043	077	127	193	275
17	000	001	002	005	013	026	049	085	135	201
18	000	000	001	003	007	015	030	055	092	143
19	000	000	001	002	004	009	018	035	061	098
20	000	000	000	001	002	005	011	021	039	066
21	000	000	000	000	001	003	006	013	025	043
22	000	000	000	000	001	002	004	008	015	028
23	000	000	000	000	000	001	002	004	009	017
24	000	000	000	000	000	000	001	003	005	011
25	000	000	000	000	000	000	001	001	003	006
	14	15	16	17	18	19	20	21	22	23
16	368	467	566	659	742	812	868	911	942	963
17	281	371	468	564	655	736	805	861	905	937
18	208	287	375	469	562	651	731	799	855	899
19	150	215	292	378	469	561	647	725	793	849
20	105	157	221	297	381	470	559	644	721	787
21	072	111	163	227	302	384	471	558	640	716
22	048	077	117	169	232	306	387	472	556	637
23	031	052	082	123	175	238	310	389	472	555
24	020	034	056	087	128	180	243	314	392	473
25	012	022	038	060	092	134	185	247	318	394
	24	25	26	27	28	29	30	31	32	33
16	978	987	993	996	998	999	999	1,000		
17	959	975	985	991	995	997	999	999	1,000	
18	932	955	972	983	990	994	997	998	999	1,000
19	893	927	951	969	980	988	993	996	998	999
20	843	888	922	948	966	978	987	992	995	997
21	782	838	883	917	944	963	976	985	991	994
22	712	777	832	877	913	940	959	973	983	989
23	635	708	772	827	873	908	936	956	971	981
24	554	632	704	768	823	868	904	932	953	969
25	473	553	629	700	763	818	863	900	929	950
	34	35	36	37	38	39	40	41	42	43
19	999	1,000								
20	999	999	1,000							
21	997	998	999	999	1,000					
22	994	996	998	999	999	1,000				
23	988	993	996	997	999	999	1,000			
24	979	987	992	995	997	998	999	999	1,000	
25	966	978	985	991	994	997	998	999	999	1,000

size and c, the acceptance number. Thus the sampling procedure is to accept a lot if the number of defectives d in a sample of n does not exceed c. The OC curve is defined by this procedure. If lot quality is submitted at p' percent defective, the probability of accepting the lot is $L(p')$.

$$
\begin{aligned}
L(p') &= \sum_{d=0}^{c} \binom{n}{d} (p')^d (1-p')^{n-d} \\
&= (1-p')^n + \binom{n}{1}(p')(1-p')^{n-1} + \binom{n}{2}(p')^2(1-p')^{n-2} \\
&\quad + \ldots + \binom{n}{c}(p')^c
\end{aligned}
$$

where $\binom{n}{d} = \dfrac{n!}{d!(n-d)!}$, and 0! is defined to be equal to 1.

Such calculations as the above are often cumbersome, and an approximation is desirable. Approximate answers may be obtained very rapidly by the use of the Poisson distribution, which is tabulated in Table 13.6.* The larger the n and smaller the p, the closer the approximate answer is to the true probability.

3.3.3 **Example.** What is the probability of accepting a lot whose incoming quality is 4.0% defective, using a sample of size 30 and an acceptance number $c = 1$?

$$
\begin{aligned}
L(0.04) &= \sum_{d=0}^{1} \binom{30}{d} (0.04)^d (0.96)^{30-d} \\
&= (0.96)^{30} + \frac{(30)!}{(29)!(1)!} 0.04(0.96)^{29} = 0.661
\end{aligned}
$$

Using the Poisson approximation,

$$
np' = 30 \times 0.04 = 1.20; \qquad c = 1; \qquad L(0.04) = 0.663
$$

which, in this case, is in good agreement with the correct value.

3.4 DOUBLE SAMPLING PLANS

A double sampling procedure can be characterized by the following: a sample of n_1 items are drawn from a lot; the lot is accepted if there are no more than c_1 defective items. If there are between $c_1 + 1$ and c_2 defective items, a second sample of size n_2 is drawn; the lot is accepted if there are no more than c_2 defectives in the combined sample of $n_1 + n_2$; the lot is rejected if there are more than c_2 defective items in the combined sample of $n_1 + n_2$.

Thus a lot will be accepted on the first sample if the incoming quality is very good. Similarly, a lot will be rejected on the first sample if the incoming quality is very bad. If the lot is of intermediate quality, a second sample may have to be taken. Double sampling plans have the psychological advantage of giving a second chance to doubtful lots. Furthermore, they can have the additional advantage of requiring fewer total inspections, on the average,

* Here $L(p')$ is approximately the value read out of Table 13.6 with entries c and np'.

than single sampling plans for any given quality protection. On the other side of the ledger, double sampling plans can have the following disadvantages: (1) more complex administrative duties; (2) inspectors will have variable inspection loads depending upon whether one or two samples are taken; (3) the maximum amount of inspection exceeds that for single sampling plans (which is constant).

3.4.1 OC curves for double sampling plans. A lot will be accepted if and only if (1) the number of defectives d_1 in the first sample of n_1 does not exceed c_1, i.e., $d_1 \le c_1$; (2) there are more than c_1 defectives in the first sample but no more than c_2 defectives, the total number of defectives $d_1 + d_2$, in the combined sample of $n_1 + n_2$ does not exceed c_2, i.e., if $c_1 < d_1 \le c_2$, then $d_1 + d_2 \le c_2$.

Thus for any incoming quality p', the probability of accepting the lot is

$$\begin{aligned} L(p') &= Pr\,(d_1 \le c_1, \text{ given } p') \\ &\quad + Pr\,(d_1 + d_2 \le c_2, \text{ given } c_1 < d_1 \le c_2; p') \\ &= Pr\,(d_1 \le c_1|p') + Pr\,(d_1 + d_2 \le c_2|c_1 < d_1 \le c_2; p') \end{aligned}$$

where the symbol | reads "given" and $Pr\,(d_1 \le c|p')$ reads "the probability that d is less than or equal to c, given p'."

$$\begin{aligned} L(p') &= \sum_{d_1=0}^{c_1} \binom{n_1}{d_1}(p')^{d_1}(1 - p')^{n_1-d_1} \\ &\quad + \sum_{d_1=c_1+1}^{c_2} \sum_{d_2=0}^{c_2-d_1} \binom{n_1}{d_1}(p')^{d_1}(1 - p')^{n_1-d_1} \\ &\quad \binom{n_2}{d_2}(p')^{d_2}(1 - p')^{n_2-d_2} \\ &= \sum_{d_1=0}^{c_1} \binom{n_1}{d_1}(p')^{d_1}(1 - p')^{n_1-d_1} \\ &\quad + \sum_{d_1=c_1+1}^{c_2} \Bigg[\binom{n_1}{d_1}(p')^{d_1}(1 - p')^{n_1-d_1} \\ &\quad \sum_{d_2=0}^{c_2-d_1} \binom{n_2}{d_2}(p')^{d_2}(1 - p')^{n_2-d_2}\Bigg] \end{aligned}$$

3.4.2 Example. A large lot of $\frac{3}{4}$-inch screws is submitted for sampling inspection by means of double sampling. If the first sample of 20 contains no defectives, the lot is to be accepted. If it contains more than two defectives, the lot is to be rejected. Otherwise, a second sample of 40 is to be drawn, and the lot is to be accepted if the total number of defectives in both samples does not exceed two. This plan can be characterized by the following table.

Sample	Sample size	Combined samples: Size	Acceptance number	Rejection number
First	20	20	0	3
Second	40	60	2	3

Find the probability of accepting the lot if $p' = 5\%$.

$$(1)\ \sum_{d_1=0}^{0} \binom{n_1}{d_1}(p')^{d}(1-p')^{n_1-d_1} = (1-p')^{20} = (0.95)^{20} = 0.358$$

$$(2)\ \binom{n_1}{1}(p')(1-p')^{n_1-1}\sum_{d_2=0}^{1}\binom{n_2}{d_2}(p')^{d_2}(1-p')^{n_2-d_2}$$
$$= \binom{n_1}{1}(p')(1-p')^{n_1-1}[(1-p')^{n_2} + \binom{n_2}{1}(p')(1-p')^{n_2-1}]$$
$$= \binom{20}{1}0.05(0.95)^{19}[(0.95)^{40} + \binom{40}{1}0.05(0.95)^{39}]$$
$$= 0.377[0.129 + 0.270] = 0.150$$

$$(3)\ \binom{n_1}{2}(p')^2(1-p')^{n_1-2}\sum_{d_2=0}^{0}\binom{n_2}{d_2}(p')^{d_2}(1-p')^{n_2-d_2}$$
$$= \binom{n_1}{2}(p')^2(1-p')^{n_1-2}(1-p')^{n_2}$$
$$= \binom{20}{2}(0.05)^2(0.95)^{18}(0.95)^{40} = 0.189 \times 0.129 = 0.02438$$
$$L(p') = 0.532$$

Using the Poisson approximation we have

(1) 0.368

(2)★ $(0.736 - 0.368)(0.406) = 0.368 \times 0.406 = 0.149$

(3)★ $(0.920 - 0.736)(0.135) = 0.184 \times 0.135 = 0.025$

$$L(p') = 0.542$$

3.5 MULTIPLE SAMPLING PLANS

A multiple sampling procedure can be represented on a table such as the following:

TABLE 13.7 MULTIPLE SAMPLING PLAN

Sample	Sample size	Combined samples: Size	Acceptance number	Rejection number
First	n_1	n_1	c_1	r_1
Second	n_2	$n_1 + n_2$	c_2	r_2
Third	n_3	$n_1 + n_2 + n_3$	c_3	r_3
Fourth	n_4	$n_1 + n_2 + n_3 + n_4$	c_4	r_4
Fifth	n_5	$n_1 + n_2 + n_3 + n_4 + n_5$	c_5	r_5
Sixth	n_6	$n_1 + n_2 + n_3 + n_4 + n_5 + n_6$	c_6	r_6
Seventh	n_7	$n_1 + n_2 + n_3 + n_4 + n_5 + n_6 + n_7$	c_7	$c_7 + 1$

★ The Poisson table is set up to give $\sum_{d=0}^{c}\binom{n}{d}p'^d(1-p')^{n-d}$. To get an individual term, say $\binom{n}{c}p'^c(1-p')^{n-c}$, we take

$$\sum_{d=0}^{c}\binom{n}{d}p'^d(1-p')^{n-d} - \sum_{d=0}^{c-1}\binom{n}{d}p'^d(1-p')^{n-d} = \binom{n}{c}p'^c(1-p')^{n-c}$$

A first sample of n_1 is drawn, the lot is accepted if there are no more than c_1 defectives, the lot is rejected if there are more than r_1 defectives. Otherwise a second sample of n_2 is drawn. The lot is accepted if there are no more than c_2 defectives in the combined sample of $n_1 + n_2$. The lot is rejected if there are more than r_2 defectives in the combined sample of $n_1 + n_2$. The procedure is continued in accordance with the above table. If, by the end of the sixth sample, the lot is neither accepted or rejected, a sample of n_7 is drawn. The lot is accepted if the number of defectives in the combined sample of $n_1 + n_2 + n_3 + n_4 + n_5 + n_6 + n_7$ does not exceed c_7. Otherwise, the lot is rejected. Note that $c_1 < c_2 < \ldots < c_7$ and $c_i < r_i$ for all i. Of course, plans can be devised which permit any number of samples before a decision is reached. A multiple sampling plan will generally involve less inspection, on the average, than the corresponding single or double sampling plan guaranteeing the same protection. The advantage is quite important, since inspection costs are directly related to sample sizes. On the other hand, some of the disadvantages of multiple sampling plans are: (1) they usually require higher administrative costs than single or double sampling plans; (2) the variability of inspection load introduces difficulties in scheduling inspection time; (3) higher caliber inspection personnel may be necessary to guarantee proper use of the plans; (4) adequate storage facilities must be provided for the lot while multiple sampling is being carried on.

3.6 CLASSIFICATION OF SAMPLING PLANS

Published tables of sampling plans have been classified into four categories, namely, by acceptable quality level (AQL), by lot tolerance per cent defective (LTPD), by point of control, and by average outgoing quality limit (AOQL).

3.6.1 Classification by AQL. Acceptance procedures based on the acceptable quality level (AQL) generally make use of the process average to determine the sampling plan to be used. The AQL may be viewed as the highest per cent defective that is acceptable as a process average. In normal sampling, a lot at AQL quality will have a high probability of acceptance. The probability of acceptance, $1 - \alpha$, at the AQL is usually set near the 95% point, and α is known as the producer's risk. Thus a producer has good protection against rejection of submitted lots from a process that is at the AQL or better. On the other hand, this type of classification does not specify anything about the protection the consumer has against the acceptance of a lot worse than the AQL.

3.6.2 Classification by LTPD. The lot tolerance per cent defective (LTPD) usually refers to that incoming quality above which there is a small chance that a lot will be accepted. This probability is usually taken to be near the 10% point. Thus a consumer, inspecting lots submitted from a process that is at the LTPD or worse, has a small probability of accepting such lots. This probability is known as the consumer's risk. On the other hand, this type

of classification does not specify anything about the protection the producer has against the rejection of lots better than the LTPD.

3.6.3 Classification by point of control. The point of control is the lot quality for which the probability of acceptance is 0.50. The concept here is one of splitting the risk between producer and consumer. Lots submitted from processes whose quality is better than the point of control have a probability of acceptance that is higher than 50%. Lots submitted from processes whose quality is worse than the point of control have a probability of acceptance smaller than 50%.

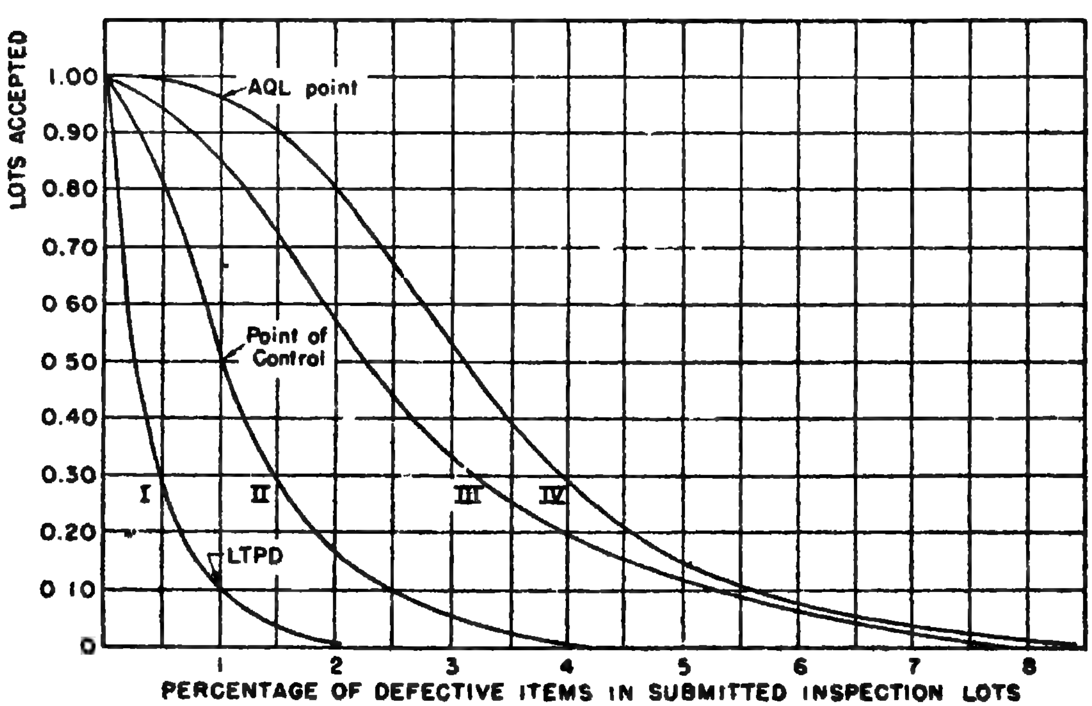
3.6.4 Classification by AOQL. The average outgoing quality limit (AOQL) does not refer to a point on the OC curve, but rather to the upper limit on outgoing quality that may be expected in the long run when all rejected lots are subjected to 100% inspection, with all defective articles removed and replaced by good articles. The average outgoing quality (AOQL) can be computed from the formulas

$$\text{AOQ} = p'L(p'); \qquad \text{AOQL} = \max_{p'} \text{AOQ}$$

where $\max_{p'}$ AOQ is the maximum AOQ over the range $p' = 0$ to p' 1.

Figure 13.14 shows a graphic comparison of these four methods of indexing acceptance plans in relation to a stated quality standard. The four curves

FIG. **13.14** SINGLE SAMPLING PLANS CLASSIFIED ON
I. 1% LTPD: $n = 225$; $c = 50$.
II. POINT OF CONTROL = 1%: $n = 50$; $c = 1$.
III. 1% AOQL: $n = 75$; $c = 1$.
IV. AQL = 1%: $n = 150$: $c = 4$.



shown in this figure are OC curves for single sampling plans that are indexed in their respective tables by the 1.0% defective figure. The most lenient plan (curve IV) is that classified by the AQL; in this plan with an AQL of 1.0%, four defectives are permitted in a sample of 150. The strictest plan (curve I) is the LTPD plan permitting 0 defectives in a sample of 225. The point of control plan (curve II) permits 1 defective in a sample of 150; here the probability of acceptance of a 1.0% defective lot is 0.50. The 1.0% AOQL plan allows 1 defective in a sample of 75; the OC curve (curve III) is intermediate between the AQL 1.0% and the point of control 1.0% plans.

3.7 DODGE-ROMIG TABLES

In 1944, H. F. Dodge and H. G. Romig published a volume of attribute sampling tables called *Sampling Inspection Tables.*★ These tables originated in the Bell Telephone Laboratories and reflect many years of experience with acceptance sampling in the Bell Telephone System. It should be pointed out that these tables were originally prepared for use within the Bell Telephone System. They were designed primarily to minimize the total amount of inspection, considering total sampling inspection and screening inspection of rejected lots. The Dodge-Romig volume contains four sets of tables, as follows:

(1) Single Sampling Lot Tolerance Tables
(2) Double Sampling Lot Tolerance Tables
(3) Single Sampling AOQL Tables
(4) Double Sampling AOQL Tables.

3.7.1 Single sampling lot tolerance tables. This set indexes plans according to the following lot tolerance per cent defectives (LTPD) with the consumer's risk = 0.10.

0.5%	2.0%	4.0%	7.0%
1.0%	3.0%	5.0%	10.0%

Table 13.8 presents a typical table from Dodge-Romig single sampling LTPD. All the sampling plans in this table have the same LTPD. Furthermore, if rejected lots are screened, the table gives the AOQL values for each plan. For any given lot size there is a choice of six plans, each for a different value of the process average. If the plan chosen corresponds to the true process average of the production process, and rejected lots are screened, the plan will guarantee that the average amount of inspection, considering inspection of samples and screening of rejected lots, will be smaller than for any of the remaining five plans.† The process average is usually estimated from past data by taking the ratio of the total number of defectives to the total number inspected. If there are no past data to estimate the process average, the plan

★ H. F. Dodge and H. G. Romig, *Sampling Inspection Tables* (New York: John Wiley and Sons, Inc., 1944).

† The average amount of inspection (AOI) is given by the formula

$$\text{AOI} = nL(p') + N[1 - L(p')].$$

TABLE 13.8 EXAMPLE OF DODGE-ROMIG SINGLE SAMPLING LOT TOLERANCE TABLES

Lot tolerance per cent defective = 5.0%; consumer's risk = 0.10.

Process average %	0–0.05			0.06–0.50			0.51–1.00			1.01–1.50			1.51–2.00			2.01–2.50		
Lot size	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %	n	c	AOQL %
1–30	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
31–50	30	0	0.49	30	0	0.49	30	0	0.49	30	0	0.49	30	0	0.49	30	0	0.49
51–100	37	0	0.63	37	0	0.63	37	0	0.63	37	0	0.63	37	0	0.63	37	0	0.63
101–200	40	0	0.74	40	0	0.74	40	0	0.74	40	0	0.74	40	0	0.74	40	0	0.74
201–300	43	0	0.74	43	0	0.74	70	1	0.92	70	1	0.92	95	2	0.99	95	2	0.99
301–400	44	0	0.74	44	0	0.74	70	1	0.99	100	2	1.0	120	3	1.1	145	4	1.1
401–500	45	0	0.75	75	1	0.95	100	2	1.1	100	2	1.1	125	3	1.2	150	4	1.2
501–600	45	0	0.76	75	1	0.98	100	2	1.1	125	3	1.2	150	4	1.3	175	5	1.3
601–800	45	0	0.77	75	1	1.0	100	2	1.2	130	3	1.2	175	5	1.4	200	6	1.4
801–1,000	45	0	0.78	75	1	1.0	105	2	1.2	155	4	1.4	180	5	1.4	225	7	1.5
1,001–2,000	45	0	0.80	75	1	1.0	130	3	1.4	180	5	1.6	230	7	1.7	280	9	1.8
2,001–3,000	75	1	1.1	105	2	1.3	135	3	1.4	210	6	1.7	280	9	1.9	370	13	2.1
3,001–4,000	75	1	1.1	105	2	1.3	160	4	1.5	210	6	1.7	305	10	2.0	420	15	2.2
4,001–5,000	75	1	1.1	105	2	1.3	160	4	1.5	235	7	1.8	330	11	2.0	440	16	2.2
5,001–7,000	75	1	1.1	105	2	1.3	185	5	1.7	260	8	1.9	350	12	2.2	490	18	2.4
7,001–10,000	75	1	1.1	105	2	1.3	185	5	1.7	260	8	1.9	380	13	2.2	535	20	2.5
10,001–20,000	75	1	1.1	135	3	1.4	210	6	1.8	285	9	2.0	425	15	2.3	610	23	2.6
20,001–50,000	75	1	1.1	135	3	1.4	235	7	1.9	305	10	2.1	470	17	2.4	700	27	2.7
50,001–100,000	75	1	1.1	160	4	1.6	235	7	1.9	355	12	2.2	515	19	2.5	770	30	2.8

should be selected from the right-hand column of the table. This gives good lots a better chance of acceptance.

It must be emphasized that if screening of rejected lots does not take place, these plans still guarantee a stated LTPD.

3.7.2 Double sampling lot tolerance tables. This set indexes plans according to the same LTPD's as for the single sampling LTPD plans. A typical double sampling LTPD table is shown in Table 13.9.

This table has the same features as the single sampling LTPD tables with the exception of using double sampling instead of single sampling. The first sample is always smaller than the corresponding single sampling plan, but if a second sample is required, the combined sample size exceeds the sample size of the single sampling plan. However, the average amount of sampling inspection is generally smaller with the double sampling plan. Since the sec-

TABLE 13.9 EXAMPLE OF DODGE-ROMIG DOUBLE SAMPLING LOT TOLERANCE TABLES

Lot tolerance per cent defective = 5.0%; consumer's risk = 0.10.

Process average %	0–0.05						0.06–0.50						2.01–2.50					
	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %	Trial 1		Trial 2			AOQL in %
Lot size	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–30	All	0	..	..	.	0	All	0	..	..	.	0	All	0	..	..		0
31–50	30	0	..	..	.	0.49	30	0	..	..	.	0.49	30	0	..	..	.	0.49
51–75	38	0	..	..	.	0.59	38	0	..	..	.	0.59	38	0	..	..	.	0.59
76–100	44	0	21	65	1	0.64	44	0	21	65	1	0.64	44	0	21	65	1	0.64
101–200	49	0	26	75	1	0.84	49	0	26	75	1	0.84	49	0	51	100	2	0.91
201–300	50	0	30	80	1	0.91	50	0	30	80	1	0.91	50	0	100	150	4	1.1
301–400	55	0	30	85	1	0.92	55	0	55	110	2	1.1	85	0	105	190	6	1.3
401–500	55	0	30	85	1	0.93	55	0	55	110	2	1.1	85	1	140	225	7	1.4
501–600	55	0	30	85	1	0.94	55	0	60	115	2	1.1	85	1	165	250	8	1.5
601–800	55	0	35	90	1	0.95	55	0	65	120	2	1.1	120	2	185	305	10	1.6
801–1,000	55	0	35	90	1	0.96	55	0	65	120	2	1.1	120	2	210	330	11	1.7
1,001–2,000	55	0	35	90	1	0.98	55	0	95	150	3	1.3	175	4	260	435	15	2.0
2,001–3,000	55	0	65	120	2	1.2	55	0	95	150	3	1.3	205	5	375	580	21	2.3
3,001–4,000	55	0	65	120	2	1.2	55	0	95	150	3	1.3	230	6	420	650	24	2.4
4,001–5,000	55	0	65	120	2	1.2	55	0	95	150	3	1.4	255	7	445	700	26	2.5
5,001–7,000	55	0	65	120	2	1.2	55	0	95	150	3	1.4	255	7	495	750	28	2.6
7,001–10,000	55	0	65	120	2	1.2	55	0	120	175	4	1.5	280	8	540	820	31	2.7
10,001–20,000	55	0	65	120	2	1.2	55	0	120	175	4	1.5	280	8	660	940	36	2.8
20,001–50,000	55	0	65	120	2	1.2	55	0	150	205	5	1.7	305	9	745	1050	41	2.9
50,001–100,000	55	0	65	120	2	1.2	55	0	150	205	5	1.7	330	10	810	1140	45	3.0

ond sample is not always taken (depending on the submitted quality), the process average is usually estimated from the first sample only.

3.7.3 Single sampling AOQL tables. This set indexes plans according to the following average outgoing quality limits (AOQL).

0.1%	1.5%	4.0%
0.25%	2.0%	5.0%
0.5%	2.5%	7.0%
0.75%	3.0%	10.0%
1.0%		

A typical single sampling AOQL table is shown in Table 13.10.

TABLE 13.10 EXAMPLE OF DODGE-ROMIG SINGLE SAMPLING AOQL TABLES

Average outgoing quality limit = 2.0%.

Process average %	0–0.04			0.05–0.40			0.41–0.80			0.81–1.20			1.21–1.60			1.61–2.00		
Lot size	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%	n	c	p_t%
1–15	All	0	...	All	0	....	All	0	....	All	0	...	All	0	....	All	0	....
16–50	14	0	13.6	14	0	13.6	14	0	13.6	14	0	13.6	14	0	13.6	14	0	13.6
51–100	16	0	12.4	16	0	12.4	16	0	12.4	16	0	12.4	16	0	12.4	16	0	12.4
101–200	17	0	12.2	17	0	12.2	17	0	12.2	17	0	12.2	35	1	10.5	35	1	10.5
201–300	17	0	12.3	17	0	12.3	17	0	12.3	37	1	10.2	37	1	10.2	37	1	10.2
301–400	18	0	11.8	18	0	11.8	38	1	10.0	38	1	10.0	38	1	10.0	60	2	8.5
401–500	18	0	11.9	18	0	11.9	39	1	9.8	39	1	9.8	60	2	8.6	60	2	8.6
501–600	18	0	11.9	18	0	11.9	39	1	9.8	39	1	9.8	60	2	8.6	60	2	8.6
601–800	18	0	11.9	40	1	9.6	40	1	9.6	65	2	8.0	65	2	8.0	85	3	7.5
801–1,000	18	0	12.0	40	1	9.6	40	1	9.6	65	2	8.1	65	2	8.1	90	3	7.4
1,001–2,000	18	0	12.0	41	1	9.4	65	2	8.2	65	2	8.2	95	3	7.0	120	4	6.5
2,001–3,000	18	0	12.0	41	1	9.4	65	2	8.2	95	3	7.0	120	4	6.5	180	6	5.8
3,001–4,000	18	0	12.0	42	1	9.3	65	2	8.2	95	3	7.0	155	5	6.0	210	7	5.5
4,001–5,000	18	0	12.0	42	1	9.3	70	2	7.5	125	4	6.4	155	5	6.0	245	8	5.3
5,001–7,000	18	0	12.0	42	1	9.3	95	3	7.0	125	4	6.4	185	6	5.6	280	9	5.1
7,001–10,000	42	1	9.3	70	2	7.5	95	3	7.0	155	5	6.0	220	7	5.4	350	11	4.8
10,001–20,000	42	1	9.3	70	2	7.6	95	3	7.0	190	6	5.6	290	9	4.9	460	14	4.4
20,001–50,000	42	1	9.3	70	2	7.6	125	4	6.4	220	7	5.4	395	12	4.5	720	21	3.9
50,001–100,000	42	1	9.3	95	3	7.6	160	5	5.9	290	9	4.9	505	15	4.2	955	27	3.7

All the sampling plans in this table have the same AOQL, assuming all rejected lots are screened. Furthermore, the table gives the LTPD values for each plan. Like all the Dodge-Romig plans these plans have the property that the average amount of inspection is smallest for that plan which belongs to the class under whose heading the true process average falls.

3.7.4 Double sampling AOQL tables. This set indexes plans according to the same AOQL's as for the single sampling AOQL plans. A typical double sampling AOQL table is shown in Table 13.11.

TABLE 13.11 EXAMPLE OF DODGE-ROMIG DOUBLE SAMPLING AOQL TABLES

Average outgoing quality limit = 2.0%.

Process average %	0–0.04						0.05–0.40						1.61–2.00					
	Trial 1		Trial 2				Trial 1		Trial 2				Trial 1		Trial 2			
Lot size	n_1	c_1	n_2	n_1+n_2	c_2	p_t%	n_1	c_1	n_2	n_1+n_2	c_2	p_t%	n_1	c_1	n_2	n_1+n_2	c_2	p_t%
1–15	All	0	..	..	.	...	All	0	..	..	.	...	All	0	..	..	.	...
16–50	14	0	..	..	.	13.6	14	0	..	..	.	13.6	14	0	..	..	.	13.6
51–100	21	0	12	33	1	11.7	21	0	12	33	1	11.7	23	0	23	46	2	10.9
101–200	24	0	13	37	1	11.0	24	0	13	37	1	11.0	27	0	28	55	2	9.6
201–300	26	0	15	41	1	10.4	26	0	15	41	1	10.4	32	0	48	80	3	8.4
301–400	26	0	16	42	1	10.3	26	0	16	42	1	10.3	36	0	69	105	4	7.6
401–500	27	0	16	43	1	10.3	30	0	35	65	2	9.0	60	1	90	150	6	7.0
501–600	27	0	16	43	1	10.3	31	0	34	65	2	8.9	65	1	95	160	6	6.8
601–800	27	0	17	44	1	10.2	31	0	39	70	2	8.8	70	1	120	190	7	6.4
801–1,000	27	0	17	44	1	10.2	32	0	38	70	2	8.7	70	1	145	215	8	6.2
1,001–2,000	33	0	37	70	2	8.5	33	0	37	70	2	8.5	110	2	205	315	11	5.5
2,001–3,000	34	0	41	75	2	8.2	34	0	41	75	2	8.2	160	3	310	470	15	4.7
3,001–4,000	34	0	41	75	2	8.2	38	0	62	100	3	7.3	235	5	415	650	20	4.3
4,001–5,000	34	0	41	75	2	8.2	38	0	62	100	3	7.3	275	6	475	750	23	4.2
5,001–7,000	35	0	40	75	2	8.1	38	0	62	100	3	7.3	280	6	575	855	26	4.1
7,001–10,000	35	0	40	75	2	8.1	38	0	62	100	3	7.3	320	7	645	965	29	4.0
10,001–20,000	35	0	40	75	2	8.1	39	0	66	105	3	7.2	395	9	835	1,230	37	3.9
20,001–50,000	35	0	40	75	2	8.1	43	0	92	135	4	6.6	480	11	1,090	1,570	46	3.7
50,001–100,000	35	0	45	80	2	8.0	43	0	92	135	4	6.6	580	13	1,460	2,040	58	3.5

This table has the same features as the single sampling AOQL tables with the exception of using double sampling instead of single sampling.

3.8 MILITARY STANDARD 105A

There have been various sets of published sampling tables using the AQL as an index. The first set of tables was developed in 1943 for Army Ordnance, and with some changes and extensions, became the Army Service Forces tables, used during the final years of World War II.

An Administration Manual, *Standard Sampling Inspection Procedures*, was issued by the Navy in October, 1945. This manual, including tables and OC (operating characteristic) curves for all the acceptance sampling plans given, had been prepared by the Statistical Research Group of Columbia University during World War II. Although the tables and procedures in this manual were similar in many respects to those of the Army Service Forces, sequential (multiple) sampling plans were included in addition to single and double sampling plans, and there were several other important points of difference. The actual tables from this manual were issued by the Navy Department in April, 1946, as Appendix X to *General Specifications for Inspection of Material.* After the unification of the armed services, Appendix X was adopted by the Department of Defense in February, 1949, as JAN-STD 105.

In 1949, a book entitled *Sampling Inspection*, edited by H. A. Freeman, M. Friedman, F. Mosteller, and W. A. Wallis* was published. This book was prepared by the Statistical Research Group of Columbia University, and with a few minor differences, the tables in *Sampling Inspection* are identical with JAN-STD 105.

JAN-STD 105 has now been superseded by MILITARY STANDARD 105A, *Sampling Procedures and Tables for Inspection by Attributes*, adopted in September, 1950, and printed for general use in December, 1950. It is evident that the new standard is likely to be used in the acceptance inspection of many billions of dollars' worth of items purchased by Army, Navy, and Air Force. Moreover, like its predecessors, MIL-STD-105A will doubtless have a great influence on acceptance procedures used in industry.

MIL-STD-105A is available for private use and is for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Most of the remaining paragraphs in this section on sampling inspection by attributes will be concerned with a discussion of this document.

3.8.1 Classification of defects. Defects are grouped into three classes, i.e., critical, major, and minor. A critical defect "is one that judgment and experience indicate could result in hazardous or unsafe conditions for individuals using or maintaining the product; or for major end item units of product, such as ships, aircraft, or tanks, a defect that could prevent performance of their tactical functions." A major defect "is a defect, other than critical,

* H. A. Freeman, M. Friedman, F. Mosteller, and W. A. Wallis, *Sampling Inspection* (New York: McGraw-Hill Book Company, Inc., 1946).

that could result in failure, or materially reduce the usability of the unit of product for its intended purpose." A minor defect "is one that does not materially reduce the usability of the unit of product for its intended purpose, or is a departure from established standards having no significant bearing on the effective use or operation of the unit."

3.8.2 Acceptable quality levels. The acceptable quality level (AQL) "is a nominal value expressed in terms of per cent defective or defects per hundred units, whichever is applicable, specified for a given group of defects of a product." The distinction between a defect and a defective is readily seen if we define a defective item as one containing one or more defects. If the percentage defective is relatively small, more than one defect will occur on an item infrequently. Consequently, in this case, the mathematical theory using defects is essentially equivalent to using defectives. The values of the AQL's are

0.015	0.25	2.5	25.0	250.0
0.035	0.40	4.0	40.0	400.0
0.065	0.65	6.5	65.0	650.0
0.10	1.0	10.0	100.0	1000.0
0.15	1.5	15.0	150.0	

Here AQL values of 10.0 or less are expressed either in per cent defective or in defects per hundred units; those over 10.0 are expressed in defects per hundred units only. These points are approximately in geometric progression and multiples of 1, 1.5, 2.5, 4.0, and 6.5. The probabilities of acceptance of submitted lots having these AQL's range from about 0.80 for the smallest sample sizes to about 0.998 for the largest sample sizes. The particular AQL values to be used for a given product "shall be specified by the Government. The Government may, at its option, specify a separate AQL for all the defects of a given class considered collectively or for any particular type of defect considered individually. A single AQL value may be specified for the group of all defects for which a product is inspected, or separate AQL values may be specified for each of two or more subgroups of the defects."

3.8.3 Normal, tightened, and reduced inspection. The government determines whether to use normal, tightened, or reduced inspection at the start of a contract. During the course of a contract, the government determines whether to use normal, tightened, or reduced inspection as follows:

Normal inspection is used when the estimated process average is not outside the applicable upper and lower limits shown in Table 13.12. These limits are obtained from the relation

$$\text{upper limit} = \text{AQL} + 3\sqrt{\frac{\text{AQL}(100 - \text{AQL})}{n}}$$

$$\text{lower limit} = \text{AQL} - 3\sqrt{\frac{\text{AQL}(100 - \text{AQL})}{n}}$$

where AQL is read in per cent.

Tightened inspection is instituted when the estimated process average exceeds the applicable upper limit shown in Table 13.12. Normal inspection is reinstated when the estimated process average is equal to or less than the

TABLE **13.12** LIMITS OF THE PROCESS AVERAGE

(Lower limits for AQL's from 0.015 to 4.0; MIL-STD-105A)

Number of sample units included in estimated process average	Acceptable quality levels											
	0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0
25–34	★	★	★	★	★	★	★	★	★	★	★	★
35–49	★	★	★	★	★	★	★	★	★	★	★	★
50–74	★	★	★	★	★	★	★	★	★	★	★	★
75–99	★	★	★	★	★	★	★	★	★	★	★	★
100–124	★	★	★	★	★	★	★	★	★	★	★	★
125–149	★	★	★	★	★	★	★	★	★	★	★	★
150–199	★	★	★	★	★	★	★	★	★	★	★	★
200–249	★	★	★	★	★	★	★	★	★	★	★	★
250–299	★	★	★	★	★	★	★	★	★	★	★	0.38
300–349	★	★	★	★	★	★	★	★	★	★	★	0.67
350–399	★	★	★	★	★	★	★	★	★	★	0.05	0.90
400–449	★	★	★	★	★	★	★	★	★	★	0.20	1.09
450–549	★	★	★	★	★	★	★	★	★	★	0.38	1.32
550–649	★	★	★	★	★	★	★	★	★	★	0.56	1.55
650–749	★	★	★	★	★	★	★	★	★	0.11	0.71	1.73
750–899	★	★	★	★	★	★	★	★	★	0.22	0.85	1.91
900–1,099	★	★	★	★	★	★	★	★	0.05	0.34	1.00	2.10
1,100–1,299	★	★	★	★	★	★	★	★	0.13	0.44	1.13	2.27
1,300–1,499	★	★	★	★	★	★	★	0.004	0.20	0.52	1.23	2.40
1,500–1,699	★	★	★	★	★	★	★	0.045	0.25	0.58	1.31	2.50
1,700–1,899	★	★	★	★	★	★	★	0.080	0.29	0.63	1.41	2.59
1,900–2,249	★	★	★	★	★	★	★	0.119	0.34	0.69	1.46	2.68
2,250–2,749	★	★	★	★	★	★	0.021	0.166	0.40	0.77	1.55	2.80
2,750–3,499	★	★	★	★	★	★	0.061	0.217	0.46	0.84	1.65	2.93
3,500–4,999	★	★	★	★	★	0.020	0.109	0.279	0.54	0.94	1.77	3.08
5,000–6,999	★	★	★	★	★	0.056	0.155	0.338	0.61	1.03	1.89	3.23
7,000–8,999	★	★	★	★	0.020	0.188	0.188	0.380	0.66	1.09	1.97	3.33
9,000–10,999	★	★	★	0.005	0.034	0.100	0.210	0.408	0.70	1.13	2.03	3.40
11,000–13,499	★	★	★	0.015	0.046	0.116	0.230	0.434	0.73	1.17	2.08	3.46
13,500–17,499	★	★	0.003	0.024	0.057	0.129	0.248	0.456	0.76	1.20	2.12	3.52
17,500–22,499	★	★	0.011	0.033	0.068	0.144	0.266	0.479	0.79	1.24	2.16	3.58
22,500 and up	★	0.003	0.021	0.045	0.083	0.163	0.290	0.510	0.83	1.29	2.23	3.65

TABLE 13.12 LIMITS OF THE PROCESS AVERAGE *(Continued)*

(Lower limits for AQL's from 6.5 to 1000.0; MIL-STD-105A)

Number of sample units included in estimated process average	Acceptable quality levels											
	6.5	10.0	15.0	25.0	40.0	65.0	100.0	150.0	250.0	400.0	650.0	1,000.0
25–34	★	★	★	★	5.07	20.47	44.8	82.4	162.7	289.5	509.2	825.3
35–49	★	★	★	1.86	10.72	27.67	53.7	93.3	176.8	307.4	532.0	853.6
50–74	★	★	0.25	5.95	15.90	34.28	61.9	103.3	189.8	323.8	552.9	879.5
75–99	★	★	2.54	8.92	19.66	39.07	67.8	110.6	199.1	335.7	568.0	898.3
100–124	★	1.04	4.02	10.83	22.07	42.14	71.7	115.3	205.2	343.3	577.7	910.4
125–149	★	1.89	5.07	12.18	23.79	44.33	74.4	118.6	209.5	348.7	584.7	918.9
150–199	0.71	2.82	6.20	13.64	25.61	46.69	77.3	122.2	214.1	354.6	592.1	928.2
200–249	1.40	3.67	7.24	14.99	27.34	48.86	80.0	125.5	218.3	360.0	599.0	936.7
250–299	1.88	4.27	7.99	15.95	28.55	50.40	81.9	127.8	221.4	363.8	603.8	942.7
300–349	2.25	4.73	8.55	16.67	29.47	51.57	83.3	129.6	223.7	366.7	607.5	947.3
350–399	2.55	5.10	9.00	17.25	30.17	52.50	84.5	131.0	225.5	369.0	610.5	951.0
400–449	2.79	5.40	9.36	17.72	30.79	53.26	85.4	132.2	227.0	370.9	612.9	954.0
450–549	3.08	5.76	9.80	18.29	31.51	54.18	86.6	133.6	228.8	373.2	615.8	957.6
550–649	3.38	6.13	10.25	18.87	32.25	55.12	87.7	135.0	230.6	375.5	618.8	961.3
650–749	3.61	6.41	10.61	19.33	32.83	55.86	88.7	136.1	232.1	377.3	621.1	964.1
750–899	3.84	6.70	10.95	19.78	33.39	56.58	89.6	137.2	233.5	379.1	623.4	967.0
900–1,099	4.08	7.00	11.32	20.26	34.00	57.35	90.5	138.4	235.0	381.0	625.8	970.0
1,100–1,299	4.29	7.26	11.64	20.67	34.52	58.02	91.3	139.4	236.3	382.7	627.9	972.6
1,300–1,499	4.46	7.46	11.89	20.99	34.93	58.53	92.0	140.2	237.3	384.0	629.6	974.6
1,500–1,699	4.59	7.63	12.09	21.25	35.26	58.95	92.5	140.8	238.1	385.0	630.9	976.3
1,700–1,899	4.70	7.76	12.26	21.46	35.53	59.30	92.9	141.3	238.8	385.9	632.0	†
1,900–2,249	4.82	7.92	12.45	21.71	35.83	59.69	93.4	141.9	239.6	386.8	†	†
2,250–2,749	4.97	8.10	12.68	22.00	36.21	60.16	94.0	142.7	240.5	†	†	†
2,750–3,499	5.13	8.30	12.92	22.32	36.61	60.67	94.6	143.4	†	†	†	†
3,500–4,999	5.33	8.54	13.22	22.70	37.09	61.29	95.4	†	†	†	†	†
5,000–6,999	5.51	8.78	13.50	23.06	37.55	61.88	†	†	†	†	†	†
7,000–8,999	5.64	8.94	13.70	23.32	37.88	†	†	†	†	†	†	†
9,000–10,999	5.73	9.05	13.84	23.50	†	†	†	†	†	†	†	†
11,000–13,499	5.82	9.15	13.96	†	†	†	†	†	†	†	†	†
13,500–17,499	5.89	9.24	†	†	†	†	†	†	†	†	†	†
17,500–22,499	5.96	†	†	†	†	†	†	†	†	†	†	†
22,500 and up	†	†	†	†	†	†	†	†	†	†	†	†

★ Number of sample units included in estimated process average is insufficient for reduced inspection.
† Number of sample units included in estimated process average is too great. Discard older results.

TABLE **13.12** LIMITS OF THE PROCESS AVERAGE (*Continued*)

(Upper limits for AQL's from 0.015 to 4.0; MIL-STD-105A)

Number of sample units included in estimated process average	Acceptable quality levels											
	0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0
25–34	‡	‡	‡	‡	‡	‡	‡	5.103	6.52	8.27	11.23	15.05
35–49	‡	‡	‡	‡	‡	‡	3.328	4.383	5.63	7.17	9.82	13.26
50–74	‡	‡	‡	‡	‡	2.155	2.810	3.722	4.81	6.17	8.52	11.62
75–99	‡	‡	‡	‡	1.396	1.858	2.434	3.243	4.22	5.44	7.59	10.43
100–124	‡	‡	‡	0.996	1.248	1.667	2.193	2.935	3.83	4.97	6.98	9.67
125–149	‡	‡	‡	0.911	1.143	1.532	2.021	2.716	3.56	4.64	6.55	9.13
150–199	‡	‡	0.644	0.818	1.030	1.386	1.836	2.481	3.27	4.28	6.09	8.54
200–249	‡	0.410	0.575	0.733	0.926	1.251	1.666	2.264	3.00	3.95	5.67	8.00
250–299	‡	0.374	0.527	0.673	0.851	1.155	1.545	2.110	2.81	3.72	5.36	7.62
300–349	0.219	0.347	0.490	0.627	0.795	1.083	1.453	1.993	2.67	3.54	5.13	7.33
350–399	0.205	0.325	0.460	0.590	0.750	1.025	1.380	1.900	2.55	3.40	4.95	7.10
400–449	0.193	0.307	0.436	0.561	0.714	0.978	1.321	1.824	2.46	3.28	4.80	6.91
450–549	0.179	0.286	0.407	0.525	0.670	0.921	1.249	1.732	2.34	3.14	4.62	6.68
550–649	0.165	0.264	0.377	0.488	0.625	0.863	1.175	1.638	2.23	3.00	4.44	6.45
650–749	0.151	0.247	0.354	0.459	0.589	0.817	1.117	1.564	2.13	2.89	4.29	6.27
750–899	0.143	0.231	0.331	0.430	0.555	0.772	1.061	1.492	2.04	2.78	4.15	6.09
900–1,099	0.131	0.213	0.307	0.400	0.518	0.724	1.000	1.415	1.95	2.66	4.00	5.90
1,100–1,299	0.121	0.197	0.286	0.374	0.485	0.683	0.948	1.348	1.87	2.56	3.87	5.73
1,300–1,499	0.113	0.185	0.270	0.354	0.461	0.651	0.907	1.296	1.80	2.48	3.77	5.60
1,500–1,699	0.107	0.175	0.256	0.337	0.440	0.625	0.874	1.25[illegible]	1.75	2.42	3.69	5.50
1,700–1,899	0.102	0.167	0.245	0.324	0.424	0.604	0.847	1.220	1.71	2.37	3.59	5.41
1,900–2,249	0.096	0.158	0.233	0.308	0.405	0.579	0.817	1.181	1.66	2.31	3.54	5.32
2,250–2,749	0.089	0.147	0.218	0.290	0.383	0.550	0.779	1.134	1.60	2.23	3.45	5.20
2,750–3,499	0.081	0.136	0.202	0.270	0.358	0.518	0.739	1.083	1.54	2.16	3.35	5.07
3,500–4,999	0.071	0.121	0.182	0.246	0.328	0.480	0.691	1.021	1.46	2.06	3.23	4.92
5,000–6,999	0.062	0.108	0.164	0.222	0.300	0.444	0.645	0.962	1.39	1.97	3.11	4.77
7,000–8,999	0.056	0.098	0.151	0.206	0.280	0.418	0.612	0.920	1.34	1.91	3.03	4.67
9,000–10,999	0.052	0.091	0.142	0.195	0.266	0.400	0.590	0.892	1.30	1.87	2.97	4.60
11,000–13,499	0.048	0.085	0.133	0.185	0.254	0.384	0.570	0.866	1.27	1.83	2.92	4.54
13,500–17,499	0.044	0.080	0.127	0.176	0.243	0.371	0.552	0.844	1.24	1.80	2.88	4.48
17,500–22,499	0.041	0.075	0.119	0.167	0.232	0.356	0.534	0.821	1.21	1.76	2.84	4.42
22,500 and up	0.036	0.067	0.109	0.155	0.217	0.337	0.510	0.790	1.17	1.71	2.77	4.35

TABLE **13.12** LIMITS OF THE PROCESS AVERAGE (*Concluded*)

(Upper limits for AQL's from 6.5 to 1,000.0; MIL-STD-105A)

Number of sample units included in estimated process average	Acceptable quality levels											
	6.5	10.0	15.0	25.0	40.0	65.0	100.0	150.0	250.0	400.0	650.0	1,000.0
25–34	20.58	27.47	36.39	52.62	74.93	109.53	155.2	217.6	337.3	510.5	790.8	1,174.7
35–49	18.30	24.64	32.93	48.14	69.28	102.33	146.3	206.7	323.2	492.6	768.0	1,146.4
50–74	16.21	22.05	29.75	44.05	64.10	95.72	138.1	196.7	310.2	476.2	747.1	1,120.5
75–99	14.70	20.17	27.46	41.08	60.34	90.93	132.2	189.4	300.9	464.3	732.0	1,101.7
100–124	13.73	18.96	25.98	39.17	57.93	87.86	128.3	184.7	294.8	456.7	722.3	1,089.6
125–149	13.03	18.11	24.93	37.82	56.21	85.67	125.6	181.4	290.5	451.3	715.3	1,081.1
150–199	12.29	17.18	23.80	36.36	54.36	83.31	122.7	177.8	285.9	445.4	707.9	1,071.8
200–249	11.60	16.33	22.76	35.01	52.66	81.14	120.0	174.5	281.7	440.0	701.0	1,063.3
250–299	11.12	15.73	22.01	34.05	51.45	79.60	118.1	172.2	278.6	436.2	696.2	1,057.3
300–349	10.75	15.27	21.45	33.33	50.53	78.43	116.7	170.4	276.3	433.3	692.5	1,052.7
350–399	10.45	14.90	21.00	32.75	49.83	77.50	115.5	169.0	274.5	431.0	689.5	1,049.0
400–449	10.21	14.60	20.64	32.28	49.21	76.74	114.6	167.8	273.0	429.1	687.1	1,046.0
450–549	9.92	14.24	20.20	31.71	48.49	75.82	113.4	166.4	271.2	426.8	684.2	1,042.4
550–649	9.62	13.87	19.75	31.13	47.75	74.88	112.3	165.0	269.4	424.5	681.2	1,038.7
650–749	9.39	13.59	19.39	30.67	47.17	74.14	111.3	163.9	267.9	422.7	678.9	1,035.9
750–899	9.16	13.30	19.05	30.22	46.61	73.42	110.4	162.8	266.5	420.9	676.6	1,033.0
900–1,099	8.92	13.00	18.68	29.74	46.00	72.65	109.5	161.6	265.0	419.0	674.2	1,030.0
1,100–1,299	8.71	12.74	18.36	29.33	45.48	71.98	108.7	160.6	263.7	417.3	672.1	1,027.4
1,300–1,499	8.54	12.54	18.11	29.01	45.07	71.47	108.0	159.8	262.7	416.0	670.4	1,025.4
1,500–1,699	8.41	12.37	17.91	28.75	44.74	71.05	107.5	159.2	261.9	415.0	669.1	1,023.7
1,700–1,899	8.30	12.24	17.74	28.54	44.47	70.70	107.1	158.7	261.2	414.1	668.0	†
1,900–2,249	8.18	12.08	17.55	28.29	44.17	70.31	106.6	158.1	260.4	413.2	†	†
2,250–2,749	8.03	11.90	17.32	28.00	43.79	69.84	106.0	157.3	259.5	†	†	†
2,750–3,499	7.87	11.70	17.08	27.68	43.39	69.33	105.4	156.6	†	†	†	†
3,500–4,999	7.67	11.46	16.78	27.30	42.91	68.71	104.6	†	†	†	†	†
5,000–6,999	7.49	11.22	16.50	26.94	42.45	68.12	†	†	†	†	†	†
7,000–8,999	7.36	11.06	16.30	26.68	42.12	†	†	†	†	†	†	†
9,000–10,999	7.27	10.95	16.16	26.50	†	†	†	†	†	†	†	†
11,000–13,499	7.18	10.85	16.04	†	†	†	†	†	†	†	†	†
13,500–17,499	7.11	10.76	†	†	†	†	†	†	†	†	†	†
17,500–22,499	7.04	†	†	†	†	†	†	†	†	†	†	†
22,500 and up	†	†	†	†	†	†	†	†	†	†	†	†

‡ Normal inspection for these AQL's does not provide sample sizes this small.
† Number of sample units included in estimated process average is too great. Discard older results.

AQL while tightened inspection is in effect. Under tightened inspection, the producer's risk is increased, whereas the consumer's risk is decreased. In other words, the probability of accepting bad lots (as well as good lots) is decreased. This is accomplished by reducing the acceptance numbers while keeping the sample size fixed.

Reduced inspection is instituted, if the government so desires, provided that all the following conditions are satisfied.

"Condition A. The preceding 10 lots have been under normal inspection and none have been rejected.
Condition B. The estimated process average is less than the applicable lower limit shown in Table 13.12.
Condition C. Production is at a steady rate."

Normal inspection is reinstated if any one of the following conditions occur while reduced inspection is in effect.

"Condition A. A lot is rejected.
Condition B. The estimated process average is greater than the AQL.
Condition C. Production becomes irregular or delayed.
Condition D. The Government deems that normal inspection should be reinstated."

Under reduced inspection, the sample size is decreased, thereby increasing the consumer's risk and decreasing (slightly) the producer's risk.

The use of tightened and reduced inspection is an important feature in the success of MIL-STD-105A. If quality is submitted close to but above the AQL, there is still a relatively large probability that it will be accepted. Although this appears to be harmful on the surface, in reality, it is not too damaging. In the first place, rejected lots cost the manufacturer a great deal of money. In fact, too many rejected lots can easily force a manufacturer out of business. For example, few manufacturers can tolerate even a 20% rejection rate for their lots. Second, if lots are constantly being submitted above the AQL, this will be reflected in the process average, which results in tightened inspection. This will cause even more of the manufacturer's lots to be rejected. Consequently, the manufacturer is actually forced to keep his submitted quality better than the agreed-upon level.

On the other hand, if the manufacturer continues to submit quality a great deal better than the AQL, the government is able to use reduced inspection, which results in a saving of inspection costs.

3.8.4 Sampling plans. Sample sizes are designated by code letters from A to Q. The sample size code letter depends on the inspection level and the lot size. There are three inspection levels, I, II, and III. Unless the government specifies otherwise, inspection level II is used. The sample size code letter applicable to the specified inspection level and for lots of given size is obtained from Table 13.13.

TABLE 13.13 SAMPLE SIZE CODE LETTERS
(MIL-STD-105A)

Lot size	Inspection levels		
	I	II	III
2 to 8	A	A	C
9 to 15	A	B	D
16 to 25	B	C	E
26 to 40	B	D	F
41 to 65	C	E	G
66 to 110	D	F	H
111 to 180	E	G	I
181 to 300	F	H	J
301 to 500	G	I	K
501 to 800	H	J	L
801 to 1,300	I	K	L
1,301 to 3,200	J	L	M
3,201 to 8,000	L	M	N
8,001 to 22,000	M	N	O
22,001 to 110,000	N	O	P
110,001 to 550,000	O	P	Q
550,001 and over	P	Q	Q

Since it has been pointed out that the OC curves are essentially independent of lot size (for large lots), it may appear incongruous that one of the entries to the table is lot size. However, a moment's reflection will reveal that to the inspection agency the acceptance of a bad lot is much more serious when the lot size is large compared with when it is small. Consequently, better protection in the form of steeper OC curves is desired for large lots.

The appropriate master sampling table is selected as follows:

For normal or tightened inspection

- AQL values of 10.0 or less
  - Single sampling: Table 13.14.
  - Double sampling: MIL-STD-105A, pp. 12-13.
  - Multiple sampling: MIL-STD-105A, pp. 14-15.
- AQL values of greater than 10.0
  - Single sampling: Table 13.14.

For reduced inspection and for all AQL values

- Single sampling: Table 13.15.

The Standard contains the OC curve for each of the plans. Each OC curve corresponds to a single sampling plan, double sampling plan, and multiple sampling plan.

3.9 DESIGNING YOUR OWN ATTRIBUTE PLAN

In many cases, it will not be desirable to select a plan according to the standard procedure of MIL-STD-105A, implying, as it does, a rather arbitrary relation between lot size and sample size. If the characteristics of

TABLE 13.14 MASTER TABLE FOR NORMAL AND TIGHTENED INSPECTION (Single sampling; MIL-STD-105A)

Sample size code letter	Sample size	Acceptable quality levels (normal inspection)																									
		0.015		0.035		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5	
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A	2	↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓	
B	3	↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		0	1
C	5	↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		0	1	↑	
D	7	↓		↓		↓		↓		↓		↓		↓		↓		↓		↓		0	1	↑		↓	
E	10	↓		↓		↓		↓		↓		↓		↓		↓		↓		0	1	↑		↓		1	2
F	15	↓		↓		↓		↓		↓		↓		↓		↓		0	1	↑		↓		1	2	2	3
G	25	↓		↓		↓		↓		↓		↓		↓		0	1	↑		↓		1	2	2	3	3	4
H	35	↓		↓		↓		↓		↓		↓		0	1	↑		↓		1	2	2	3	3	4	5	6
I	50	↓		↓		↓		↓		↓		0	1	↑		↓		1	2	2	3	3	4	4	5	6	7
J	75	↓		↓		↓		↓		0	1	↑		↓		1	2	2	3	3	4	4	5	6	7	9	10
K	110	↓		↓		↓		0	1	↑		↓		1	2	2	3	3	4	4	5	6	7	8	9	12	13
L	150	↓		↓		0	1	↑		↓		1	2	2	3	3	4	4	5	5	6	8	9	11	12	17	18
M	225	↓		0	1	↑		↓		1	2	2	3	3	4	4	5	5	6	8	9	11	12	17	18	24	25
N	300	0	1	↑		↓		1	2	2	3	3	4	4	5	5	6	7	8	10	11	14	15	20	21	32	33
O	450	↑		↓		1	2	2	3	3	4	4	5	5	6	7	8	10	11	14	15	20	21	29	30	43	44
P	750	↓		1	2	2	3	3	4	4	5	6	7	8	9	11	12	15	16	20	21	31	32	45	46	68	69
Q	1,500	1	2	2	3	3	4	5	6	7	8	9	10	13	14	18	19	25	26	35	36	56	57	81	82	124	125
		0.035		0.065		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10.0	
		Acceptable quality levels (tightened inspection)																									

Sample size code letter	Sample size	Acceptable quality levels (normal inspection)																					
		10.0		15.0		25.0		40.0		65.0		100.0		150.0		250.0		400.0		650.0		1000.0	
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A	2	0	1	↓		↓		1	2	2	3	3	4	5	6	8	9	12	13	19	20	28	29
B	3	↕				1	2	2	3	3	4	5	6	8	9	12	13	18	19	28	29	41	42
C	5			1	2	2	3	3	4	5	6	8	9	12	13	19	20	29	30	44	45	65	66
D	7	1	2	2	3	3	4	5	6	7	8	11	12	17	18	26	27	39	40	60	61	89	90
E	10	2	3	3	4	5	6	7	8	10	11	15	16	23	24	36	37	54	55	83	84	123	124
F	15	3	4	4	5	7	8	10	11	15	16	22	23	33	34	51	52	78	79	121	122	178	179
G	25	5	6	7	8	11	12	16	17	24	25	35	36	51	52	80	81	124	125	192	193	↑	
H	35	7	8	10	11	15	16	22	23	33	34	48	49	69	70	110	111	168	169	↑			
I	50	9	10	13	14	20	21	30	31	46	47	67	68	96	97	151	152	↑					
J	75	13	14	19	20	29	30	43	44	66	67	96	97	138	139	↑							
K	110	18	19	26	27	40	41	60	61	93	94	135	136	↑									
L	150	24	25	34	35	53	54	80	81	123	124	↑											
M	225	34	35	48	49	76	77	115	116	↑													
N	300	44	45	63	64	98	99	↑															
O	450	62	63	89	90	↑																	
P	750	98	99	↑																			
Q	1,500	184	185																				
		15.0		25.0		40.0		65.0		100.0		150.0		250.0		400.0		650.0		1000.0			
		Acceptable quality levels (tightened inspection)																					

↓ = Use first sampling plan below arrow. When sample size equals or exceeds lot size, do 100% inspection. ↑ = Use first sampling plan above arrow. Ac = Acceptance no. Re = Rejection no. Tightened sampling plans are not provided for AQL: 0.015.

TABLE 13.15 MASTER TABLE FOR REDUCED INSPECTION (Single sampling only; MIL-STD-105A)

Sample size code letter	Sample size	0.015 Ac	0.015 Re	0.035 Ac	0.035 Re	0.065 Ac	0.065 Re	0.10 Ac	0.10 Re	0.15 Ac	0.15 Re	0.25 Ac	0.25 Re	0.40 Ac	0.40 Re	0.65 Ac	0.65 Re	1.0 Ac	1.0 Re	1.5 Ac	1.5 Re	2.5 Ac	2.5 Re	4.0 Ac	4.0 Re
A, B, C, D	2	Reduced inspection not available for AQL: 0.015		↓		↓		↓		↓		↓		↓		↓		↓		0	1	↓		↓	
E	2																			0	1				
F	3																	0	1	↑				1	2
G	5															0	1	↑		↓		1	2	1	2
H	7													0	1	↑		↓		1	2	1	2	2	3
I	10											0	1	↑		↓		1	2	1	2	2	3	2	3
J	15									0	1	↑		↓		1	2	1	2	2	3	2	3	3	4
K	22							0	1	↑		↓		1	2	1	2	2	3	2	3	3	4	4	5
L	30					0	1	↑		↓		1	2	1	2	2	3	2	3	3	4	4	5	5	6
M	45			0	1	↑		↓		1	2	1	2	2	3	2	3	3	4	4	5	5	6	7	8
N	60			↑		↓		1	2	1	2	2	3	2	3	3	4	4	5	5	6	6	7	9	10
O	90			↓		1	2	1	2	2	3	2	3	3	4	4	5	5	6	6	7	9	10	11	12
P	150			1	2	1	2	2	3	2	3	3	4	4	5	5	6	7	8	9	10	11	12	14	13
Q	300			1	2	2	3	3	4	4	5	5	6	6	7	8	9	11	12	13	14	16	17	21	22

Sample size code letter	Sample size	Acceptable quality levels																							
		6.5		10.0		15.0		25.0		40.0		65.0		100.0		150.0		250.0		400.0		650.0		1000.0	
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A, B, C, D	1					1	2	1	2	1	2	2	3	4	5	5	6	8	9	12	13	15	16	19	20
E	2	1	2	1	2	2	3	3	4	3	4	4	5	7	8	10	11	13	14	17	18	22	23	29	30
F	3	1	2	2	3	2	3	3	4	5	6	7	8	10	11	13	14	17	18	21	22	29	30	37	38
G	5	2	3	3	4	3	4	5	6	7	8	10	11	13	14	17	18	22	23	29	30	39	40	↑	
H	7	3	4	3	4	5	6	7	8	9	10	13	14	16	17	20	21	27	28	36	37	↑			
I	10	3	4	4	5	6	7	9	10	12	13	16	17	19	20	24	25	33	34	↑					
J	15	4	5	6	7	8	9	12	13	15	16	19	20	24	25	31	32	↑							
K	22	5	6	8	9	11	12	14	15	18	19	23	24	31	32	↑									
L	30	7	8	11	12	12	13	16	17	21	22	29	30	↑											
M	45	10	11	13	14	15	16	20	21	27	28	↑													
N	60	12	13	15	16	18	19	24	25	↑															
O	90	14	15	18	19	23	24	↑																	
P	150	18	19	23	24	↑																			
Q	300	28	29	37	38																				

↓ = Use first sampling plan below arrow. When sample size equals or exceeds lot size, do 100 per cent inspection. ↑ = Use first sampling plan above arrow. Ac = Acceptance number. Re = Rejection number.

TABLE **13.16** VALUES OF np'_1 FOR WHICH THE PROBABILITY OF ACCEPTANCE OF c OR FEWER DEFECTIVES IN A SAMPLE OF n IS $P(A)$★

[To find the fraction defective p', corresponding to a probability of acceptance $P(A)$ in a single sampling plan with sample size n and acceptance number c, divide by n the entry in the row for the given c and the column for the given $P(A)$].

c	$P(A) =$ 0.995	$P(A) =$ 0.990	$P(A) =$ 0.975	$P(A) =$ 0.950	$P(A) =$ 0.900	$P(A) =$ 0.750	$P(A) =$ 0.500	$P(A) =$ 0.250	$P(A) =$ 0.100	$P(A) =$ 0.050	$P(A) =$ 0.025	$P(A) =$ 0.010	$P(A) =$ 0.005
0	0.00501	0.0101	0.0253	0.0513	0.105	0.288	0.693	1.386	2.303	2.996	3.689	4.605	5.298
1	0.103	0.149	0.242	0.355	0.532	0.961	1.678	2.693	3.890	4.744	5.572	6.638	7.430
2	0.338	0.436	0.619	0.818	1.102	1.727	2.674	3.920	5.322	6.296	7.224	8.406	9.274
3	0.672	0.823	1.090	1.366	1.745	2.535	3.672	5.109	6.681	7.754	8.768	10.045	10.978
4	1.078	1.279	1.623	1.970	2.433	3.369	4.671	6.274	7.994	9.154	10.242	11.605	12.594
5	1.537	1.785	2.202	2.613	3.152	4.219	5.670	7.423	9.275	10.513	11.668	13.108	14.150
6	2.037	2.330	2.814	3.286	3.895	5.083	6.670	8.558	10.532	11.842	13.060	14.571	15.660
7	2.571	2.906	3.454	3.981	4.656	5.956	7.669	9.684	11.771	13.148	14.422	16.000	17.134
8	3.132	3.507	4.115	4.695	5.432	6.838	8.669	10.802	12.995	14.434	15.763	17.403	18.578
9	3.717	4.130	4.795	5.426	6.221	7.726	9.669	11.914	14.206	15.705	17.085	18.783	19.998
10	4.321	4.771	5.491	6.169	7.021	8.620	10.668	13.020	15.407	16.962	18.390	20.145	21.398
11	4.943	5.428	6.201	6.924	7.829	9.519	11.668	14.121	16.598	18.208	19.682	21.490	22.779
12	5.580	6.099	6.922	7.690	8.646	10.422	12.668	15.217	17.782	19.442	20.962	22.821	24.145
13	6.231	6.782	7.654	8.464	9.470	11.329	13.668	16.310	18.958	20.668	22.230	24.139	25.496
14	6.893	7.477	8.396	9.246	10.300	12.239	14.668	17.400	20.128	21.886	23.490	25.446	26.836
15	7.566	8.181	9.144	10.035	11.135	13.152	15.668	18.486	21.292	23.098	24.741	26.743	28.166
16	8.249	8.895	9.902	10.831	11.976	14.068	16.668	19.570	22.452	24.302	25.984	28.031	29.484
17	8.942	9.616	10.666	11.633	12.822	14.986	17.668	20.652	23.606	25.500	27.220	29.310	30.792
18	9.644	10.346	11.438	12.442	13.672	15.907	18.668	21.731	24.756	26.692	28.448	30.581	32.092
19	10.353	11.082	12.216	13.254	14.525	16.830	19.668	22.808	25.902	27.879	29.671	31.845	33.383
20	11.069	11.825	12.999	14.072	15.383	17.755	20.668	23.883	27.045	29.062	30.888	33.103	34.668
21	11.791	12.574	13.787	14.894	16.244	18.682	21.668	24.956	28.184	30.241	32.102	34.355	35.947
22	12.520	13.329	14.580	15.719	17.108	19.610	22.668	26.028	29.320	31.416	33.309	35.601	37.219
23	13.255	14.088	15.377	16.548	17.975	20.540	23.668	27.098	30.453	32.586	34.512	36.841	38.485
24	13.995	14.853	16.178	17.382	18.844	21.471	24.668	28.167	31.584	33.752	35.710	38.077	39.745
25	14.740	15.623	16.984	18.218	19.717	22.404	25.667	29.234	32.711	34.916	36.905	39.308	41.000
26	15.490	16.397	17.793	19.058	20.592	23.338	26.667	30.300	33.836	36.077	38.096	40.535	42.252
27	16.245	17.175	18.606	19.900	21.469	24.273	27.667	31.365	34.959	37.234	39.284	41.757	43.497

28	17.004	17.957	19.422	20.746	22.348	25.209	28.667	32.428	36.080	38.389	40.468	42.975	44.738
29	17.767	18.742	20.241	21.594	23.229	26.147	29.667	33.491	37.198	39.541	41.649	44.190	45.976
30	18.534	19.532	21.063	22.444	24.113	27.086	30.667	34.552	38.315	40.690	42.827	45.401	47.210
31	19.305	20.324	21.888	23.298	24.998	28.025	31.667	35.613	39.430	41.838	44.002	46.609	48.440
32	20.079	21.120	22.716	24.152	25.885	28.966	32.667	36.672	40.543	42.982	45.174	47.813	49.666
33	20.856	21.919	23.546	25.010	26.774	29.907	33.667	37.731	41.654	44.125	46.344	49.015	50.888
34	21.638	22.721	24.379	25.870	27.664	30.849	34.667	38.788	42.764	45.266	47.512	50.213	52.108
35	22.422	23.525	25.214	26.731	28.556	31.792	35.667	39.845	43.872	46.404	48.676	51.409	53.324
36	23.208	24.333	26.052	27.594	29.450	32.736	36.667	40.901	44.978	47.540	49.840	52 601	54.538
37	23.998	25.143	26.891	28.460	30.345	33.681	37.667	41.957	46.083	48.676	51.000	53.791	55.748
38	24.791	25.955	27.733	29.327	31.241	34.626	38.667	43.011	47.187	49.808	52.158	54.979	56.956
39	25.586	26.770	28.576	30.196	32.139	35.572	39.667	44.065	48.289	50.940	53.314	56.164	58.160
40	26.384	27.587	29.422	31.066	33.038	36.519	40.667	45.118	49.390	52.069	54.469	57.347	59.363
41	27.184	28.406	30.270	31.938	33.938	37.466	41.667	46.171	50.490	53.197	55.622	58.528	60.563
42	27.986	29.228	31.120	32.812	34.839	38.414	42.667	47.223	51.589	54.324	56.772	59.717	61.761
43	28.791	30.051	31.970	33.686	35.742	39.363	43.667	48.274	52.686	55.449	57.921	60.884	62.956
44	29.598	30.877	32.824	34.563	36.646	40.312	44.667	49.325	53.782	56.572	59.068	62.059	64.150
45	30.408	31.704	33.678	35.441	37.550	41.262	45.667	50.375	54.878	57.695	60.214	63.231	65.340
46	31.219	32.534	34.534	36.320	38.456	42.212	46.667	51.425	55.972	58.816	61.358	64.402	66.529
47	32.032	33.365	35.392	37.200	39.363	43.163	47.667	52.474	57.065	59.936	62.500	65.571	67.716
48	32.848	34.198	36.250	38.082	40.270	44.115	48.667	53.522	58.158	61.054	63.641	66.738	68.901
49	33.664	35.032	37.111	38.965	41.179	45.067	49.667	54.571	59.249	62.171	64.780	67.903	70.084

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TABLE 13.17 VALUES OF np_1 AND c FOR CONSTRUCTING SINGLE SAMPLING PLANS WHOSE OC CURVE IS REQUIRED TO PASS THROUGH THE TWO POINTS $(p_1, 1 - \alpha)$ AND (p_2, β) *

(Here p_1 is the fraction defective for which the risk of rejection is to ba α and p_2 is the fraction defective for which the risk of acceptance is to be β. To construct the plan, find the tabular value of p_2/p_1 in the column for the given α and β which is equal to or just less than the given value of the ratio. The sample size is found by dividing the np_1 corresponding to the selected ratio by p_1. The acceptance number is the value of c corresponding to the selected value of the ratio).

c	Values of p_2/p_1 for: $\alpha = 0.05$, $\beta = 0.10$	$\alpha = 0.05$, $\beta = 0.05$	$\alpha = 0.05$, $\beta = 0.01$	np_1	c	Values of p_2/p_1 for: $\alpha = 0.01$, $\beta = 0.10$	$\alpha = 0.01$, $\beta = 0.05$	$\alpha = 0.01$, $\beta = 0.01$	np_1
0	44.890	58.404	89.781	0.052	0	229.105	298.073	458.210	0.010
1	10.946	13.349	18.681	0.355	1	26.184	31.933	44.686	0.149
2	6.509	7.699	10.280	0.818	2	12.206	14.439	19.278	0.436
3	4.890	5.675	7.352	1.366	3	8.115	9.418	12.202	0.823
4	4.057	4.646	5.890	1.970	4	6.249	7.156	9.072	1.279
5	3.549	4.023	5.017	2.613	5	5.195	5.889	7.343	1.785
6	3.206	3.604	4.435	3.286	6	4.520	5.082	6.253	2.330
7	2.957	3.303	4.019	3.981	7	4.050	4.524	5.506	2.906
8	2.768	3.074	3.707	4.695	8	3.705	4.115	4.962	3.507
9	2.618	2.895	3.462	5.426	9	3.440	3.803	4.548	4.130
10	2.497	2.750	3.265	6.169	10	3.229	3.555	4.222	4.771
11	2.397	2.630	3.104	6.924	11	3.058	3.354	3.959	5.428
12	2.312	2.528	2.968	7.690	12	2.915	3.188	3.742	6.099
13	2.240	2.442	2.852	8.464	13	2.795	3.047	3.559	6.782
14	2.177	2.367	2.752	9.246	14	2.692	2.927	3.403	7.477
15	2.122	2.302	2.665	10.035	15	2.603	2.823	3.269	8.181
16	2.073	2.244	2.588	10.831	16	2.524	2.732	3.151	8.895
17	2.029	2.192	2.520	11.633	17	2.455	2.652	3.048	9.616
18	1.990	2.145	2.458	12.442	18	2.393	2.580	2.956	10.346
19	1.954	2.103	2.403	13.254	19	2.337	2.516	2.874	11.082

20	1.922	2.065	2.352	14.072	20	2.287	2.458	2.790	11.825
21	1.892	2.030	2.307	14.894	21	2.241	2.405	2.733	12.574
22	1.865	1.999	2.265	15.719	22	2.200	2.357	2.671	13.329
23	1.840	1.969	2.226	16.548	23	2.162	2.313	2.615	14.088
24	1.817	1.942	2.191	17.382	24	2.126	2.272	2.564	14.853
25	1.795	1.917	2.158	18.218	25	2.094	2.235	2.516	15.623
26	1.775	1.893	2.127	19.058	26	2.064	2.200	2.472	16.397
27	1.757	1.871	2.098	19.900	27	2.035	2.168	2.431	17.175
28	1.739	1.850	2.071	20.746	28	2.009	2.138	2.393	17.957
29	1.723	1.831	2.046	21.594	29	1.985	2.110	2.358	18.742
30	1.707	1.813	2.023	22.444	30	1.962	2.083	2.324	19.532
31	1.692	1.796	2.001	23.298	31	1.940	2.059	2.293	20.324
32	1.679	1.780	1.980	24.152	32	1.920	2.035	2.264	21.120
33	1.665	1.764	1.960	25.010	33	1.900	2.013	2.236	21.919
34	1.653	1.750	1.941	25.870	34	1.882	1.992	2.210	22.721
35	1.641	1.736	1.923	26.731	35	1.865	1.973	2.185	23.525
36	1.630	1.723	1.906	27.594	36	1.848	1.954	2.162	24.333
37	1.619	1.710	1.890	28.460	37	1.833	1.936	2.139	25.143
38	1.609	1.698	1.875	29.327	38	1.818	1.920	2.118	25.955
39	1.599	1.687	1.860	30.196	39	1.804	1.903	2.098	26.770
40	1.590	1.676	1.846	31.066	40	1.790	1.887	2.079	27.587
41	1.581	1.666	1.833	31.938	41	1.777	1.873	2.060	28.406
42	1.572	1.656	1.820	32.812	42	1.765	1.859	2.043	29.228
43	1.564	1.646	1.807	33.686	43	1.753	1.845	2.026	30.051
44	1.556	1.637	1.796	34.563	44	1.742	1.832	2.010	30.877
45	1.548	1.628	1.784	35.441	45	1.731	1.820	1.994	31.704
46	1.541	1.619	1.773	36.320	46	1.720	1.808	1.980	32.534
47	1.534	1.611	1.763	37.200	47	1.710	1.796	1.965	33.365
48	1.527	1.603	1.752	38.082	48	1.701	1.785	1.952	34.198
49	1.521	1.596	1.743	38.965	49	1.691	1.775	1.938	35.032

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an OC curve are specified in advance, it is possible to determine the sample size and acceptance number accordingly. This article will deal with procedures for determining sampling plans when two points are specified, and with finding the OC curve of an arbitrary sampling plan.

3.9.1 Computing the OC curve of a single sampling plan. In Art. 3.3.2 a method for computing the OC curve of a single sampling plan with sample size n and acceptance number c was presented. The OC curve may also be constructed from Table 13.16 by dividing each entry in the row for the given c by the sample size. The fraction defective p' for which the probability of acceptance is shown in the column heading, is obtained.

Example. For $n = 75$, $c = 4$; find the OC curve.

Dividing the numbers in the row $c = 4$ by 75 we find the following 13 points on the OC curve.

Probability of acceptance	Fraction defective	Probability of acceptance	Fraction detective
0.995	$\frac{1.078}{75} = 0.01437$	0.250	$\frac{6.274}{75} = 0.08365$
0.990	$\frac{1.279}{75} = 0.01705$	0.100	$\frac{7.994}{75} = 0.1066$
0.975	$\frac{1.623}{75} = 0.02164$	0.050	$\frac{9.154}{75} = 0.1221$
0.950	$\frac{1.970}{75} = 0.02627$	0.025	$\frac{10.242}{75} = 0.1372$
0.900	$\frac{2.433}{75} = 0.03244$	0.010	$\frac{11.605}{75} = 0.1547$
0.750	$\frac{3.369}{75} = 0.04492$	0.005	$\frac{12.594}{75} = 0.1679$
0.500	$\frac{4.671}{75} = 0.06228$		

3.9.2 Finding a sampling plan whose OC curve passes through two points. As pointed out in Art. 3.3, it is often useful to specify two points on an OC curve; p'_1 and p'_2 such that $L(p'_1) = 1 - \alpha$ and $L(p'_2) = \beta$. Here p'_1 is usually denoted as acceptable quality (quality we want to accept) and p'_2 usually represents unacceptable quality (quality we want to reject). Hence α and β are usually taken as small numbers, 0.01, 0.05, or 0.10. For these values, sampling plans may be found in Table 13.17. To construct a plan for a given p'_1, α and p'_2, β, calculate the ratio p'_2/p'_1 and find the entry in the appropriate α, β column which is equal to or just greater than the desired ratio. The acceptance number is read off directly and the sample size is determined by dividing np'_1 by p'_1.

Example. $p'_1 = 0.02$, $p'_2 = 0.04$, $\alpha = 0.05$, $\beta = 0.05$. Find n and c.

$$\frac{p'_2}{p'_1} = \frac{0.04}{0.02} = 2$$

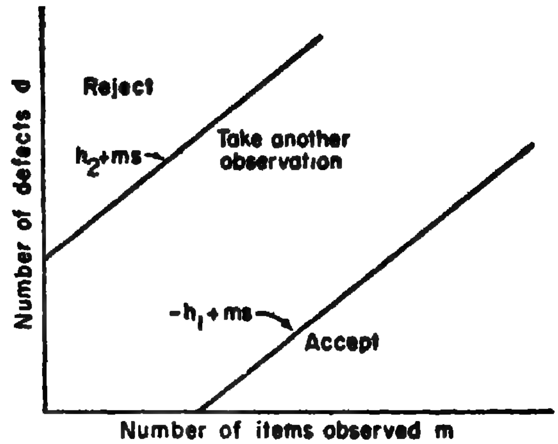


FIG. **13.15** GRAPHIC PROCEDURE FOR ITEM BY ITEM SEQUENTIAL SAMPLING PLAN.

The value in the table just greater than 2 is 2.030. Hence, $c = 21$, $n = 14.894/0.02 = 745$.

3.9.3 **Design of item-by-item sequential plans.** It is not possible to give simple formulas for the acceptance and rejection numbers in double or multiple sampling plans; however, simple formulas do exist for item-by-item sequential plans, i.e., plans in which the decision to accept, reject, or continue sampling is made after each observation. The plan can be represented graphically as a pair of parallel lines (Fig. 13.15). The plan is determined by the acceptance line $a_m = -h_1 + ms$ and the rejection line $r_m = h_2 + ms$. To calculate h_1, h_2, and s, we introduce the quantities

$$b = \ln\frac{1-\alpha}{\beta}; \quad a = \ln\frac{1-\beta}{\alpha}; \quad g_1 = \ln\frac{p_2'}{p_1'}; \quad g_2 = \ln\frac{1-p_1'}{1-p_2'}$$

Then

$$h_1 = \frac{b}{g_1+g_2}; \quad h_2 = \frac{a}{g_1+g_2}; \quad s = \frac{g_2}{g_1+g_2}$$

Example. Suppose we want $p_1' = 0.01$, $p_2' = 0.10$, $\alpha = 0.05$, $\beta = 0.20$; we calculate

$$b = \ln\frac{0.95}{0.20} = 1.55815; \quad a = \ln\frac{0.80}{0.05} = 2.77259$$

$$g_1 = \ln\frac{0.10}{0.01} = 2.30258; \quad g_2 = \ln\frac{0.99}{0.90} = 0.09531$$

$$h_1 = 0.649796; \qquad h_2 = 1.156407; \qquad s = 0.039747$$

and get the equations

$$a_m = -0.649796 + 0.039747m; \qquad r_m = 1.156407 + 0.039747m$$

Usually the sequential plan is applied in a tabular rather than graphical form; a_m and r_m are computed for every m and listed in Table 13.18. Note that a_m is rounded down to the nearest integer and r_m is rounded up to the nearest integer.

TABLE 13.18 TABULAR PROCEDURE FOR ITEM-BY-ITEM SEQUENTIAL SAMPLING PLAN

Number of observations m	Acceptance number a_m	Rejection number r_m	Observed number of defects d
1	...	...	
2	...	...	
3	...	2	
⋮	⋮	⋮	
17	0	2	
⋮	⋮	⋮	
22	0	3	
⋮	⋮	⋮	
42	0	3	
⋮	⋮	⋮	
47	1	4	
⋮	⋮	⋮	
67	2	4	
⋮	⋮	⋮	
72	2	5	
⋮	⋮	⋮	
97	3	6	
⋮	⋮	⋮	
117	4	6	
⋮	⋮	⋮	
122	4	7	
⋮	⋮	⋮	
143	5	7	
⋮	⋮	⋮	
148	5	8	

Simple formulas may be found for the probability of acceptance and the expected number of observations from five values of the fraction defective including the two points defining the plan.

$$p' = 0; \qquad L(p') = 1; \qquad \bar{n}_0 = \frac{h_1}{s}$$

$$p' = p_1'; \qquad L(p') = 1 - \alpha; \qquad \bar{n}_{p'_1} = \frac{(1-\alpha)h_1 - \alpha h_2}{s - p_1'}$$

$$p' = s; \qquad L(p') = \frac{h_2}{h_1 + h_2}; \qquad \bar{n}_s = \frac{h_1 h_2}{s(1-s)}$$

$$p' = p_2'; \qquad L(p') = \beta; \qquad \bar{n}_{p'_2} = \frac{(1-\beta)h_2 - \beta h_1}{p_2' - s}$$

$$p' = 1; \qquad L(p') = 0; \qquad \bar{n}_1 = \frac{h_2}{1 - s}$$

In the above example,

$$p' = 0; \qquad L(0) = 1; \qquad \bar{n}_0 = \frac{0.649796}{0.039747} = 16.348$$

$$p' = 0.01; \qquad L(0.01) = 0.95;$$

$$\bar{n}_{.01} = \frac{(0.95)(0.649796) - (0.05)(1.156407)}{0.029747} = 18.808$$

$$p' = 0.039747;$$

$$L(0.039747) = \frac{1.156407}{0.649796 + 1.156407} = 0.64024;$$

$$\bar{n}_{(.039747)} = \frac{(0.649796)(1.156407)}{(0.039747)(0.960253)} = 19.688$$

$$p' = 0.10; \qquad L(0.10) = 0.20;$$

$$\bar{n}_{.10} = \frac{0.80(1.156407) - 0.20(0.649796)}{0.10 - 0.039747} = 13.197$$

$$p' = 1.00; \qquad L(1.00) = 0; \qquad \bar{n}_{1.00} = \frac{1.156407}{0.960253} = 1.2043$$

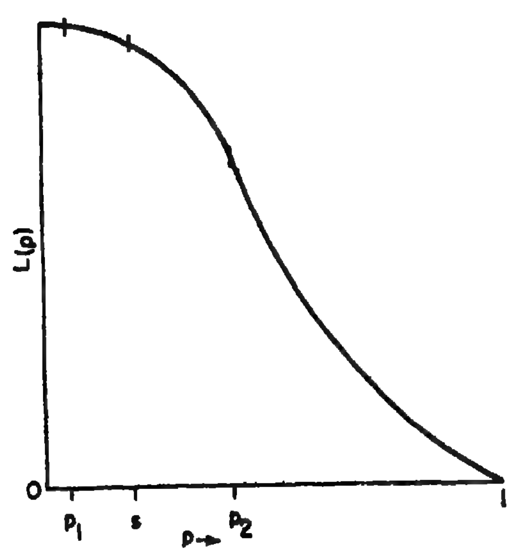


FIG. 13.16 OC CURVE OF SEQUENTIAL PLAN SKETCHED FROM FIVE POINTS.

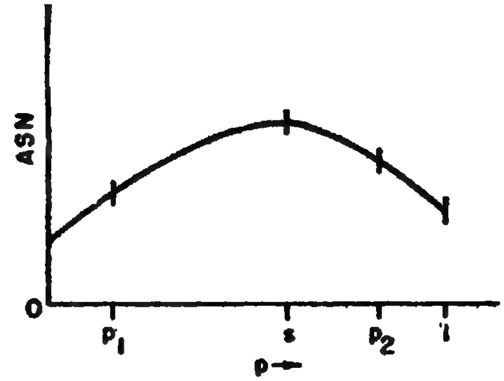


FIG. 13.17 ASN CURVE OF SEQUENTIAL PLAN SKETCHED FROM FIVE POINTS.

Usually these five points may be used to make an adequate sketch of the OC and ASN curves.

If more points are needed, they may be found by substituting values between 1 and ∞ for x in the equations

$$L(p') = \frac{x^{h_1+h_2} - x^{h_1}}{x^{h_1+h_2} - 1}; \qquad p' = \frac{x^s - 1}{x - 1}$$

The point $[p', L(p')]$ has the conjugate $[p'_c, L(p'_c)]$ given by

$$L(p'_c) = \frac{L(p')}{x^{h_1}}; \qquad p'_c = p'(x^{1-s})$$

The expected number of observations is

$$\bar{n}_{p'} = \frac{L(p')(h_1 + h_2) - h_2}{s - p'}$$

3.10 LOT-BY-LOT SAMPLING INSPECTION BY VARIABLES: INTRODUCTION

The principles underlying variables sampling inspection plans have been explained in considerable detail in *Sampling Inspection by Variables*★ by Bowker and Goode, and *Techniques of Statistical Analysis*† by Eisenhart, Hastay, and Wallis. Briefly, it is assumed that the item qualities are normally distributed about the universe mean $\bar{x}'$ with standard deviation σ' either known or unknown.

The criteria for acceptance by variables are put in the following forms.

3.11 ONE-SIDED TESTS—KNOWN σ'

For an upper specification limit U, with known σ', accept the lot if $\hat{p}_U \leq p^*$, where p^* is a preassigned constant (similar to the acceptance number) and

★ A. H. Bowker and H. P. Goode, *Sampling Inspection by Variables* (New York: McGraw-Hill Book Company, Inc., 1952).

† C. Eisenhart, M. W. Hastay, and W. A. Wallis, *Techniques of Statistical Analysis* (New York: McGraw-Hill Book Company, Inc., 1947).

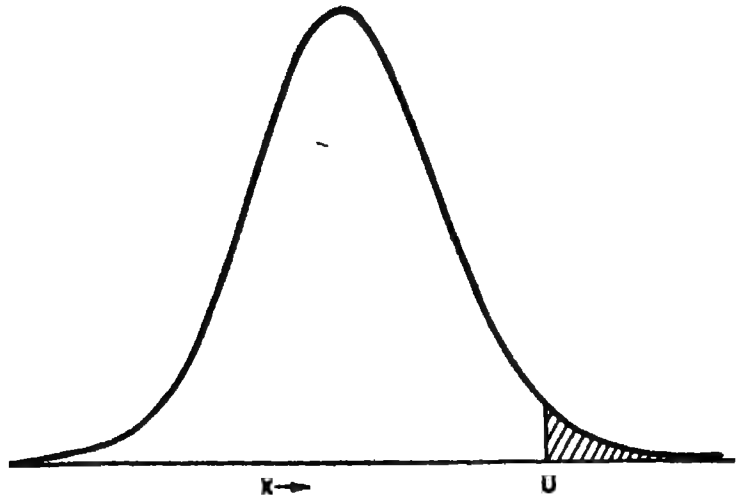
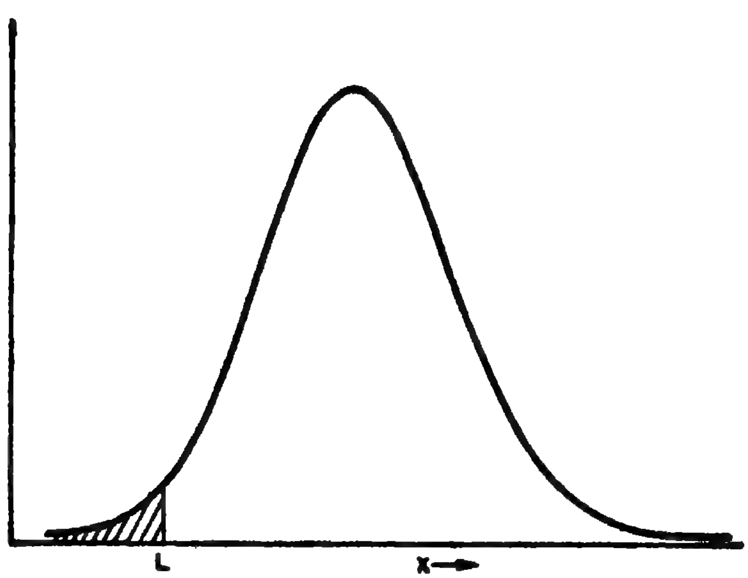


FIG. 13.18 PART OF POPULATION LYING ABOVE THE UPPER SPECIFICATION LIMIT.

$$\bullet\ \hat{p}_U = \int_{\left(\frac{U-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz$$

is an estimate of the percentage of the population, based on a sample of n items, falling above U. Then $\left(\frac{U - \bar{x}}{\sigma'}\right) \frac{\sqrt{n}}{\sqrt{n-1}}$ is computed and $\hat{p}_U$ is found by entering the table of the normal distribution (Table 13.3). As an alternative procedure, it can be shown that $\hat{p}_U \leq p^*$ if and only if $\bar{x} + k\sigma' \leq U$, where k is a constant specified by the acceptance plan, i.e., for fixed n, different values of k yield different OC curves. Hence, accept the lot if $\bar{x} + k\sigma' \leq U$; otherwise reject the lot.

FIG. 13.19 PART OF POPULATION LYING BELOW A LOWER SPECIFICATION LIMIT.



For a lower specification limit L with known σ', accept the lot if $\hat{p}_L \leq p^*$, where p^* is a preassigned constant and

$$\hat{p}_L = \int_{-\infty}^{\left(\frac{L-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz$$

is an estimate of the percentage of the population, based on a sample of n items, falling below L. Then $\left(\frac{L - \bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}$ is computed and $\hat{p}_L$ is found by entering the table of the normal distribution (Table 13.3).

Alternatively, it can be shown that $\hat{p}_L \leq p^*$ if and only if $\bar{x} - k\sigma' \geq L$. Hence, accept the lot if $\bar{x} - k\sigma' \geq L$; otherwise reject the lot.

3.12 ONE-SIDED TESTS—UNKNOWN σ'

For an upper specification limit U with unknown σ', accept the lot if $\hat{p}_U \leq p^*$, where p^* is a preassigned constant (similar to the acceptance number) and $\hat{p}_U$ is an estimate of the percentage of the population, based on a sample of n items, falling above U. If the sample standard deviation

$$s = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{\sum x_i^2 - n\bar{x}^2}{n-1}}$$

is used as an estimate of σ', then $\hat{p}_U$ is a function of $\bar{x}$, s, and U. This function has been tabulated by the Applied Mathematics and Statistics Laboratory of Stanford University and can be obtained on request. This estimate has optimum statistical properties. Alternatively, it can be shown that $\hat{p}_U \leq p^*$ if and only if $\bar{x} + ks \leq U$. Hence, accept the lot if $\bar{x} + ks \leq U$; otherwise reject the lot.

If the average range of v subgroups of 5, $\bar{R} = \sum_{i=1}^{v} R_i/v$, is used as an estimate of σ', then $\hat{p}_U$, the estimate of the percentage above U in a sample of $n = 5v$, is a function of $\bar{x}$, $\bar{R}$, and U. Again, as an alternate procedure, it can be shown that $\hat{p}_U \leq p^*$ if and only if $\bar{x} + k\bar{R}/2.3259 \leq U$. Hence, accept the lot if $\bar{x} + k\bar{R}/2.3259 \leq U$; otherwise reject the lot.

For a lower specification limit L, with unknown σ', accept the lot if $\hat{p}_L \leq p^*$, where p^* is a preassigned constant and $\hat{p}_L$ is an estimate of the percentage of the population, based on a sample of n items, falling below L. If s is used as an estimate of σ', then $\hat{p}_L$ is a function of $\bar{x}$, s, and L, and has been tabulated by the Applied Mathematics and Statistics Laboratory of Stanford University. The alternate procedure is derived from the relation $\hat{p}_L \leq p^*$ if and only if $\bar{x} - ks \geq L$. Hence, accept the lot if $\bar{x} - ks \geq L$; otherwise reject the lot.

If the average range of v subgroups of 5, $\bar{R} = \sum_{i=1}^{v} R_i/v$, is used as an esti-

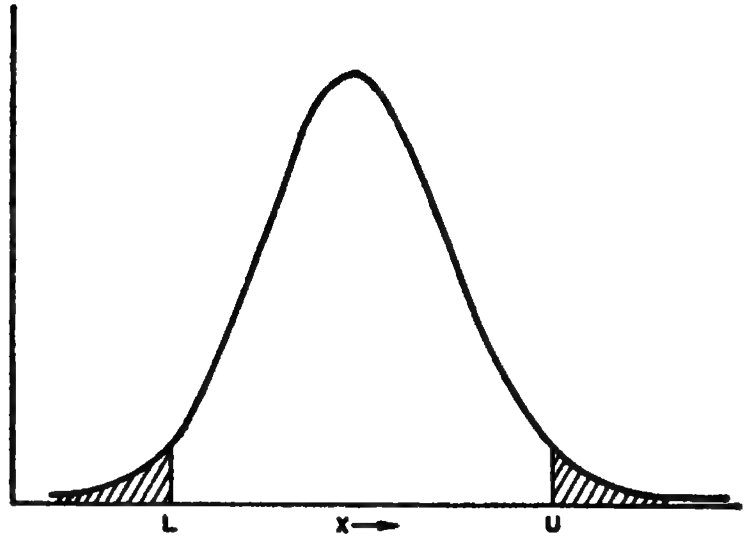


FIG. 13.20 PART OF POPULATION LYING ABOVE UPPER SPECIFICATION LIMIT AND BELOW LOWER SPECIFICATION LIMIT.

mate of σ', then $\hat{p}_L$ is a function of $\bar{x}$, $\bar{R}$, and L. Alternatively, it can be shown that $\hat{p}_L \le p^*$ if and only if $\bar{x} - k\bar{R}/2.3259 \ge L$.

3.13 TWO-SIDED TESTS—KNOWN σ'

For a two-sided specification test, with known σ', accept the lot if $\hat{p}_L + \hat{p}_U \le p^*$, where

$$\hat{p}_L = \int_{-\infty}^{\left(\frac{L-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz$$

and

$$\hat{p}_U = \int_{\left(\frac{U-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz$$

Hence, compute $\left(\frac{L-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}$ and $\left(\frac{U-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}$ and enter the tables of the normal distribution to obtain $\hat{p}_L$ and $\hat{p}_U$.

3.14 TWO-SIDED TESTS—UNKNOWN σ'

For a two-sided specification test, with unknown σ', accept the lot if $\hat{p}_L + \hat{p}_U \le p^*$, where $\hat{p}_L$ and $\hat{p}_U$ are the estimates mentioned in Art. 3.12.

3.15 VARIABLES PLANS THAT MATCH MIL-STD-105A

Table 13.19 presents one-sided unknown standard deviation variables plans based on the sample standard deviation which most closely match

TABLE 13.19 TABLE SHOWING ONE-SIDED UNKNOWN STANDARD DEVIATION VARIABLES PLANS WHICH MOST CLOSELY MATCH ATTRIBUTE PLANS IN MIL-STD-105A*

Sample size code letter	Acceptable quality levels											
	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
A												$n = 2$ $k = 0.6$
B											$n = 3$ $k = 1.0$	
C										$n = 4$ $k = 1.3$		
D									$n = 5$ $k = 1.5$			$n = 5$ $k = 0.8$
E								$n = 7$ $k = 1.6$			$n = 7$ $k = 1.0$	$n = 7$ $k = 0.6$
F							$n = 10$ $k = 1.8$			$n = 10$ $k = 1.3$	$n = 10$ $k = 1.0$	$n = 10$ $k = 0.8$
G						$n = 15$ $k = 2.0$			$n = 15$ $k = 1.5$	$n = 15$ $k = 1.3$	$n = 15$ $k = 1.1$	$n = 15$ $k = 0.8$
H					$n = 20$ $k = 2.0$			$n = 20$ $k = 1.7$	$n = 20$ $k = 1.5$	$n = 20$ $k = 1.3$	$n = 20$ $k = 1.0$	$n = 20$ $k = 0.8$
I				$n = 25$ $k = 2.25$			$n = 25$ $k = 1.8$	$n = 25$ $k = 1.7$	$n = 25$ $k = 1.5$	$n = 25$ $k = 1.3$	$n = 30$ $k = 1.1$	$n = 30$ $k = 0.8$
J			$n = 30$ $k = 2.5$			$n = 35$ $k = 2.0$	$n = 35$ $k = 1.8$	$n = 35$ $k = 1.7$	$n = 35$ $k = 1.6$	$n = 35$ $k = 1.4$	$n = 40$ $k = 1.2$	$n = 50$ $k = 1.0$
K		$n = 35$ $k = 2.5$			$n = 40$ $k = 2.25$	$n = 40$ $k = 2.0$	$n = 40$ $k = 1.8$	$n = 40$ $k = 1.7$	$n = 50$ $k = 1.6$	$n = 50$ $k = 1.4$	$n = 50$ $k = 1.2$	
L	$n = 40$ $k = 2.5$			$n = 50$ $k = 2.25$								

* Matches which require a sample size for variables plans greater than 50 are not given.

TABLE 13.20 TABLE SHOWING KNOWN STANDARD DEVIATION VARIABLES PLANS WHICH MOST CLOSELY MATCH ATTRIBUTE PLANS IN MIL-STD-105A

Sample size code letter	Acceptable quality levels											
	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
A												$n = 2$ $p^* = 17.5$
B											$n = 2$ $p^* = 10.8$	
C										$n = 2$ $p^* = 5.71$		
D									$n = 3$ $p^* = 4.43$			$n = 4$ $p^* = 18.9$
E								$n = 3$ $p^* = 2.91$			$n = 5$ $p^* = 12.7$	$n = 6$ $p^* = 22.8$
F							$n = 4$ $p^* = 1.96$			$n = 6$ $p^* = 8.22$	$n = 7$ $p^* = 15.0$	$n = 8$ $p^* = 22.1$
G						$n = 4$ $p^* = 1.10$			$n = 7$ $p^* = 4.90$	$n = 9$ $p^* = 8.83$	$n = 11$ $p^* = 12.7$	$n = 13$ $p^* = 21.0$
H					$n = 4$ $p^* = 0.788$			$n = 8$ $p^* = 3.37$	$n = 10$ $p^* = 6.21$	$n = 12$ $p^* = 9.13$	$n = 15$ $p^* = 15.0$	$n = 18$ $p^* = 20.6$
I				$n = 5$ $p^* = 0.547$			$n = 9$ $p^* = 2.32$	$n = 11$ $p^* = 4.28$	$n = 14$ $p^* = 6.23$	$n = 16$ $p^* = 8.37$	$n = 20$ $p^* = 12.4$	$n = 24$ $p^* = 18.4$
J			$n = 5$ $p^* = 0.352$			$n = 10$ $p^* = 1.53$	$n = 13$ $p^* = 2.78$	$n = 16$ $p^* = 4.08$	$n = 19$ $p^* = 5.47$	$n = 23$ $p^* = 8.22$	$n = 29$ $p^* = 12.2$	$n = 34$ $p^* = 17.7$
K		$n = 6$ $p^* = 0.238$			$n = 10$ $p^* = 1.00$	$n = 14$ $p^* = 1.37$	$n = 17$ $p^* = 2.80$	$n = 20$ $p^* = 3.73$	$n = 25$ $p^* = 5.58$	$n = 30$ $p^* = 7.41$	$n = 36$ $p^* = 11.1$	$n = 41$ $p^* = 16.7$
L	$n = 6$ $p^* = 0.165$			$n = 11$ $p^* = 0.737$	$n = 15$ $p^* = 1.35$	$n = 18$ $p^* = 2.03$	$n = 22$ $p^* = 2.70$	$n = 26$ $p^* = 3.35$	$n = 33$ $p^* = 5.40$	$n = 40$ $p^* = 7.43$	$n = 49$ $p^* = 11.5$	

TABLE 13.21 TABLE SHOWING ONE-SIDED UNKNOWN STANDARD DEVIATION VARIABLES PLANS BASED ON THE RANGE WHICH MOST CLOSELY MATCH ATTRIBUTE PLANS IN MIL-STD-105A*

Sample size code letter	Acceptable quality levels											
	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
A												$n = 2^a$ $k = 0.6$
B											$n = 3^b$ $k = 0.8$	
C										$n = 4^c$ $k = 1.2$		
D									$n = 7^d$ $k = 1.4$			$n = 7^d$ $k = 0.8$
E								$n = 10$ $k = 1.6$			$n = 7^d$ $k = 1.0$	$n = 7^d$ $k = 0.6$
F							$n = 10$ $k = 1.7$			$n = 10$ $k = 1.2$	$n = 15$ $k = 1.0$	$n = 15$ $k = 0.8$
G						$n = 15$ $k = 2.0$			$n = 15$ $k = 1.5$	$n = 20$ $k = 1.3$	$n = 20$ $k = 1.1$	$n = 20$ $k = 0.8$
H					$n = 25$ $k = 2.25$			$n = 25$ $k = 1.7$	$n = 25$ $k = 1.5$	$n = 25$ $k = 1.3$	$n = 25$ $k = 1.0$	$n = 25$ $k = 0.8$
I				$n = 20$ $k = 2.25$			$n = 25$ $k = 1.8$	$n = 30$ $k = 1.6$	$n = 30$ $k = 1.4$	$n = 35$ $k = 1.3$	$n = 35$ $k = 1.1$	$n = 35$ $k = 0.8$
J			$n = 35$ $k = 2.5$			$n = 40$ $k = 2.0$	$n = 40$ $k = 1.8$	$n = 40$ $k = 1.7$	$n = 40$ $k = 1.5$	$n = 40$ $k = 1.3$	$n = 50$ $k = 1.1$	$n = 50$ $k = 1.0$
K		$n = 35$ $k = 2.5$			$n = 50$ $k = 2.25$	$n = 50$ $k = 2.0$	$n = 50$ $k = 1.8$	$n = 50$ $k = 1.7$	$n = 50$ $k = 1.5$	$n = 50$ $k = 1.3$	$n = 50$ $k = 1.1$	
L	$n = 40$ $k = 2.5$			$n = 50$ $k = 2.25$								

★ Matches which require a sample size for variables plans greater than 50 are not given.
[a] For $n = 2$, the test criteria is of the form $\bar{x} + kR/1.128$ where R is the range of the sample of 2.
[b] For $n = 3$, the test criteria is of the form $\bar{x} + kR/1.693$ where R is the range of the sample of 3.
[c] For $n = 4$, the test criteria is of the form $\bar{x} + kR/2.059$ where R is the range of the sample of 4.
[d] For $n = 7$, the test criteria is of the form $\bar{x} + kR/2.704$ where R is the range of the sample of 7.

attribute plans in MIL-STD-105A. The criteria for accepting lots is as follows: for an upper specification limit, accept the lot if $\bar{x} + ks \leq U$; for a lower specification limit, accept the lot if $\bar{x} - ks \geq L$.

Table 13.20 presents one- and two-sided known σ' variables plans which most closely match attribute plans in MIL-STD-105A. The criteria for accepting lots is as follows: for an upper specification limit, accept the lot if

$$\hat{p}_U = \int_{\left(\frac{U-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz \leq p^*$$

for a lower specification limit, accept the lot if

$$\hat{p}_L = \int_{-\infty}^{\left(\frac{L-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz \leq p^*$$

for a two-sided specification limit, accept the lot if

$$\hat{p}_L + \hat{p}_U = \int_{-\infty}^{\left(\frac{L-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz + \int_{\left(\frac{U-\bar{x}}{\sigma'}\right)\frac{\sqrt{n}}{\sqrt{n-1}}}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz \leq p^*$$

Table 13.21 presents one-sided unknown standard deviation variables plans based on the average range which most closely match attribute plans in MIL-STD-105A. The criteria for accepting lots is as follows: for an upper specification limit, accept the lot if $\bar{x} + \dfrac{k\bar{R}}{2.3259} \leq U$; for a lower specification limit, accept the lot if $\bar{x} - \dfrac{k\bar{R}}{2.3259} \geq L$.

3.16 INTRODUCTION: CONTINUOUS SAMPLING INSPECTION

The preceding articles on sampling inspection have dealt with lot-by-lot inspection when items are classified according to attribute data or variables data. In the following articles, inspection procedures will be given for items that are not broken into lots, and that are sampled by attributes. In these continuous sampling procedures, current inspection results are used to determine whether sampling inspection or screening inspection is to be used for the next items to be inspected.

3.17 DODGE CONTINUOUS SAMPLING PLAN (CSP-1)

In 1943, Dodge published a continuous sampling plan in the *Annals of Mathematical Statistics*.★ The procedure, as stated by Dodge, is as follows:

★ H. F. Dodge, "A Sampling Inspection Plan for Continuous Production," *Annals of Mathematical Statistics*, Vol. 14, September 1943.

"(a) At the outset, inspect 100% of the units consecutively as produced and continue such inspection until i units in succession are found clear of defects.

(b) When i units in succession are found clear of defects, discontinue 100% inspection, and inspect only a fraction f of the units, selecting individual sample units one at a time from the flow of product in such a manner as to assure an unbiased sample.

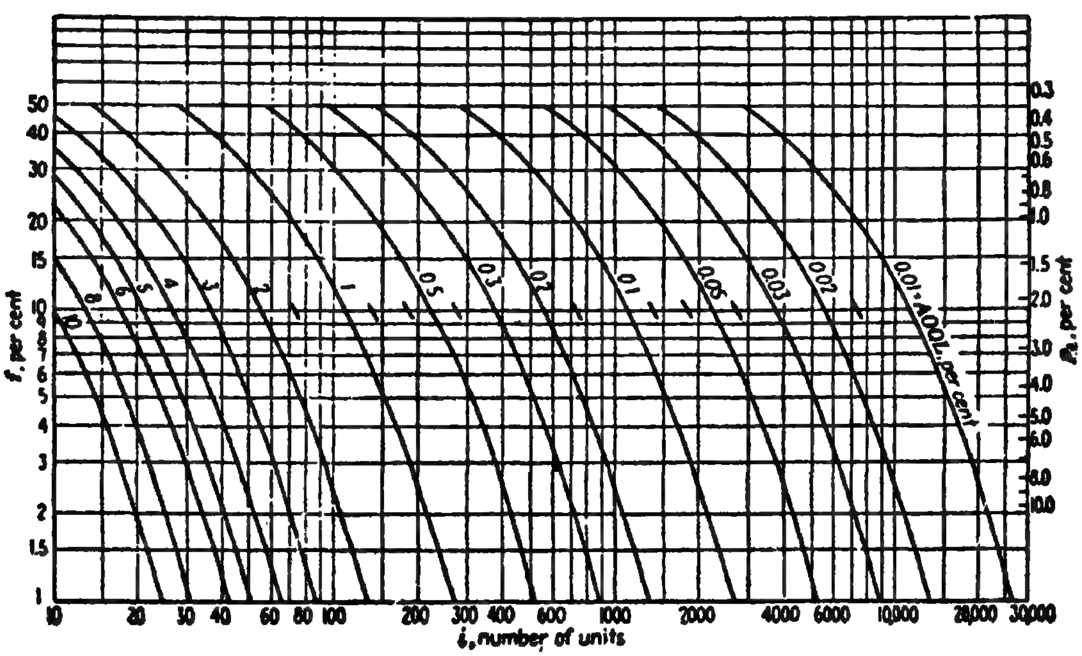
(c) If a sample unit is found defective, revert immediately to a 100% inspection of succeeding units and continue until again i units in succession are found clear of defects, as in paragraph (a).

(d) Correct or replace with good units all defective units found."

In his paper, Dodge studied the properties of this plan, and presented equations and charts for determining the average outgoing quality limit (AOQL) as functions of the parameters f and i, under the assumption that the process is in a state of statistical control. A production process is said to be in statistical control if there is a positive constant $p \leq 1$ such that, for every item produced, the probability that it is defective is p, and is independent of the state (defective or nondefective) of all the other items produced.

Figure 13.21 presents the necessary chart for the selection of the appropriate plan.

3.17.1 **Example.** Suppose the desired AOQL is 4% and f is chosen to be $\frac{1}{8}$. From Fig. 13.21, i is found to be 17. The plan is as follows:



Reproduced by permission from "A Sampling Inspection Plan for Continuous Production," by H. F. Dodge.

FIG. 13.21 CURVES FOR DETERMINING VALUES OF f AND i FOR A GIVEN VALUE OF AOQL IN DODGE'S PLAN FOR CONTINUOUS PRODUCTION.

Inspect all the units as produced and continue such inspection until 17 units in succession are found clear of defects.

When 17 units in succession are found clear of defects, discontinue 100% inspection, and inspect only one out of five units. As soon as a defective is found, revert to 100% inspection of succeeding units and continue until again 17 units in succession are found clear of defects. Then resume sampling inspection.

3.17.2 Further results with the Dodge procedure. Although the Dodge procedure is always applicable, it only guarantees the specified AOQL provided the process is in a state of statistical control. Lieberman* has shown that the Dodge procedure guarantees an AOQL whether or not the process is in a state of statistical control. In fact, without the assumption of control, and for a given f and i,

$$\text{AOQL} = \frac{1/f - 1}{1/f + i}$$

In the above example, if the assumption of control is *not* made and an AOQL of 4% is desired with $f = \frac{1}{5}$, it is necessary to take $i = 95$.

In 1951, H. F. Dodge and Miss M. N. Torrey† developed two modifications of CSP-1. They are referred to as CSP-2 and CSP-3. These plans remove the feature of reverting to 100% inspection as soon as one defect is found; instead, 100% inspection is reinstated only when one defect falls too closely on the heels of another during sampling inspection, that is, when their separation is smaller than a prescribed minimum spacing. Naturally, the probability of accepting a short run of product of poor quality is higher in these plans than in the original one. These last two plans differ in that one provides for the inspection of four additional units whenever a defect is found under conditions that do not require reinstating 100% inspection, thereby providing protection against short runs of poor product.

3.18 GIRSHICK CONTINUOUS SAMPLING PLAN

In 1948, M. A. Girshick‡ presented a continuous sampling plan. It is defined by the three integers m, N, and K. The plan operates as follows: The units of product in the production sequence are divided into segments of size K. Inspection begins by selecting at random one item from each consecutive segment of K items. The items are inspected in sequence and the number of defectives found, as well as the number of items examined, are cumulated. This procedure is continued until the cumulative number of defectives reaches m. At this point, the size of the sample n is compared with the integer N. If $n \geq N$, the product which has passed through inspection is

* G. J. Lieberman, "A Note on Dodge's Continuous Inspection Plan," *Annals of Mathematical Statistics*, Vol. 24, September 1953.

† H. F. Dodge and M. N. Torrey, "Additional Continuous Sampling Inspection Plans," *Industrial Quality Control*, Vol. 7, March 1951.

‡ M. A. Girshick, "Sampling Inspection Plans for Continuous Production," unpublished paper delivered at the May 10, 1948, meeting of the Institute of Mathematical Statistics.

considered acceptable and the inspection procedure is repeated on the new incoming product. If, on the other hand, $n < N$, the following actions are taken: (a) the next $N - n$ segments are inspected 100%; and (b) after that, the inspection procedure is repeated. This procedure always guarantees that the AOQL cannot exceed $(K - 1)m/KN$.

3.18.1 **Example.** If an AOQL of 4% is desired with $K = 5$ and $m = 3$, the value of N for the Girshick plan is found by solving the equation $0.04 = (4 \times 3)/(5N)$ for N, i.e., $N = 60$.

Thus inspection begins by selecting at random one item from each consecutive segment of five items. This procedure is continued until the cumulative number of defectives reaches three. At this point, the size of the sample n is compared with 60. If $n \geq 60$, the product that has passed through inspection is considered acceptable, and the inspection procedure is repeated on the new incoming product. If, on the other hand, $n < 60$, the next $60 - n$ segments are inspected 100%. After that, the initial inspection procedure is repeated.

4. COMMON SIGNIFICANCE TESTS

4.1 INTRODUCTION

Significance tests are important tools in scientific and industrial experimentation; they are used for making decisions on the basis of the limited information available in samples and provide procedures for making these decisions with preassigned risks. For example, an experimenter may wish to determine whether a new method of sealing vacuum tubes will increase their life, whether a new alloy will have an increased breaking strength, whether a new source of raw material has resulted in a change in the quality of output, or whether a special treatment of concrete will have an effect on breaking strength.

Consider the breaking strength example: We are really concerned with two distributions, one the distribution of breaking strength of concrete made by the standard method, and the other the distribution of concrete receiving the special treatment. Our problem is to decide whether these two distributions are the same or different, and in particular to decide if their mean breaking strengths are the same. We make the hypothesis that there is no difference in mean breaking strength, and will accept or reject this hypothesis on the basis of experimental evidence. A number of test specimens of both the special and standard treatment will be made up and the compressive strength of each test specimen determined. A statistic will be computed from these measurements.

Ideally, before the data are at hand, the experimenter should decide on his rule of rejection and on the number of items to include in the sample. As explained in the detailed instructions for the various cases included in this article, the test for the equality of two population means is based on the difference of the sample means (say h = mean of special treatment minus mean of standard treatment) divided by some measure of their sampling

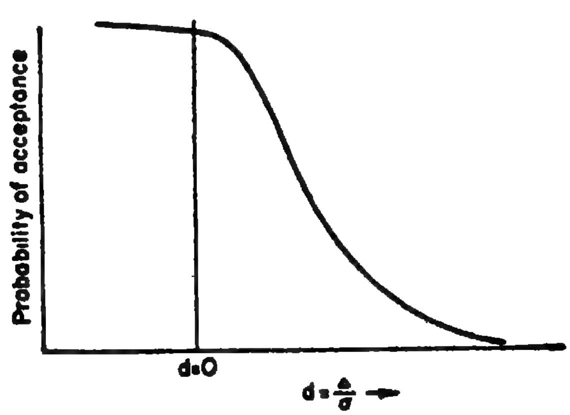
variability. In this case, we will keep the standard method of treatment unless the special method actually increases the breaking strength, and we are interested in rejecting the hypothesis of equality only in this case. Hence, we will reject the hypothesis only if the sample mean of the new material is substantially greater than the sample mean of the old, i.e., h is positive. This kind of test that rejects when differences are in one direction only is called a one-tailed test, since the region of rejection consists of one tail of the distribution of the test statistic. Often we are interested in rejecting the hypothesis of equality of means when the true means differ in either direction, as when we want to see if a new source of raw materials has changed the quality of output. In this case, we reject when the difference of the sample means is either too large or too small; such tests are called two-tailed tests.

4.2 OC CURVES OF THE TEST

Suppose we let Δ equal the true difference in true means, i.e., $\Delta =$ mean of special treatment population minus mean of standard treatment population, and we are interested in the one-tailed test. Now we have indicated that we want a test that will have a high probability of rejecting the hypothesis of equality of means for Δ positive and a high probability of accepting the hypothesis (low probability of rejecting) if $\Delta \leq 0$. Of course, in repeated sampling from populations with a given Δ we will accept some of the time and reject the rest of the time; the percentage of times we accept the hypothesis is the probability of acceptance. A plot of the probability of acceptance as a function of Δ is called the operating characteristic curve of the test; just as the protection of an acceptance sampling plan is characterized by the OC curve (the probability of accepting the lot as a function of presented quality) so the risk of making the wrong decision in any significance test is characterized by the OC curve.

An operating characteristic curve for a one-sided test will look something like Fig. 13.22. Operating characteristic curve for a two-sided test will

FIG. 13.22 OC CURVE OF THE ONE-SIDED TEST FOR THE EQUALITY OF TWO MEANS.



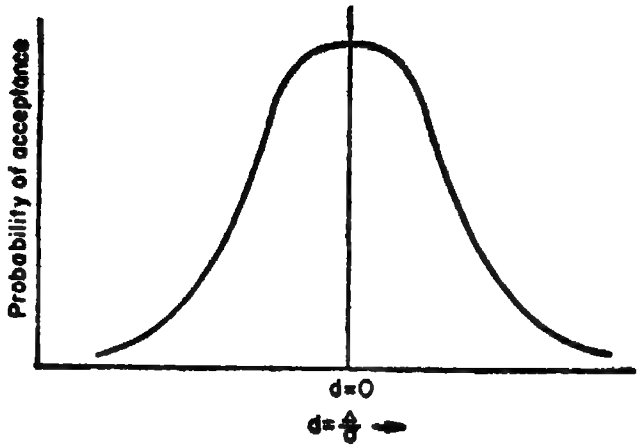


FIG. 13.23 OC CURVE OF THE TWO-SIDED TEST FOR THE EQUALITY OF TWO MEANS.

look something like Fig. 13.23. The probability of rejecting the hypothesis ($\Delta = 0$ in this case) when it is true (1 − probability of acceptance as given by the OC curve) is often called the level of significance or size of the test. The letter α will be used to denote the level of significance. Standard practice is to take α as 0.05 or 0.01 depending on how serious it is from a practical point of view to reject the hypothesis when it is true.

A family of OC curves of the one-tailed test for various values of the sample size is given in Fig. 13.24. As in the case of sampling inspection, increasing the number of observations increases the slope of the OC curve; the probability of accepting the hypothesis $\Delta = 0$ if Δ is really 0 remains the same, i.e., the significance level can be achieved for any sample size. What changes is the probability of deciding that $\Delta = 0$ if the true situation is such that the means actually differ; for any given $\Delta > 0$ the probability of accepting will decrease as n increases. To pick a sample size, the experimentalist must pick a difference Δ that is important from the practical point of view and then choose the number of observations which gives him small chance of accepting the hypothesis if the true difference is as great as the practical difference. Very often he must weigh the cost of taking additional observations

FIG. 13.24 FAMILY OF OC CURVES OF THE ONE-TAILED TEST FOR THE EQUALITY OF MEANS.

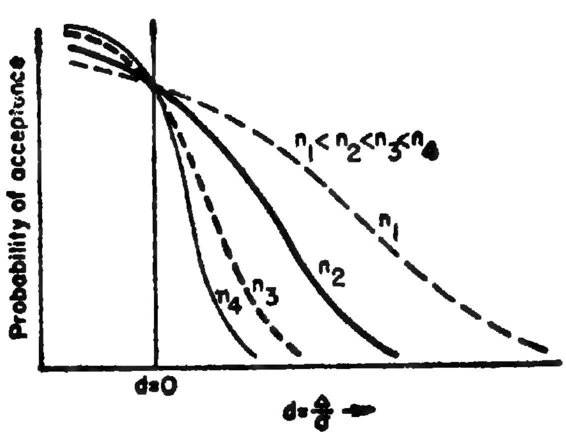


TABLE 13.22 SUMMARY OF SIGNIFICANCE TESTS: TESTING FOR THE VALUE OF A SPECIFIED PARAMETER

Hypothesis	Notation for hypothesis	Qualifying conditions	Statistic used in test	Reference to detailed explanation	Rule of rejection	Tables	Choice of sample size
The mean of a normal distribution has a specified value	$\mu = \mu_0$	known σ	$U = \dfrac{\sqrt{n}(\bar{x} - \mu_0)}{\sigma}$	Normal dist. Art. 4.4	$U \geq K_\alpha$ if we wish to reject when the true mean exceeds μ_0.	13.3	Figs. 13.27 and 13.28
					$U \leq -K_\alpha$ if we wish to reject when the true mean is less than μ_0.	13.3	Figs. 13.27 and 13.28
					$\lvert U\rvert \geq K_{\alpha/2}$ if we wish to reject when the true mean departs in either direction from μ_0.	13.3	Figs. 13.25 and 13.26
	$\mu = \mu_0$	unknown σ	$t = \dfrac{\sqrt{n}(\bar{x} - \mu_0)}{s}$	t Art. 4.5	$t \geq t_{\alpha;n-1}$ if we wish to reject when the true mean exceeds μ_0.	13.25	Figs. 13.31 and 13.32
					$t \leq -t_{\alpha;n-1}$ if we wish to reject when the true mean is less than μ_0.	13.25	Figs. 13.31 and 13.32
					$\lvert t\rvert \geq t_{\alpha/2;n-1}$ if we wish to reject when the true mean departs in either direction from μ_0.	13.25	Figs. 13.29 and 13.30
The standard deviation (or variance) of a normal distribution has a specified value	$\sigma = \sigma_0$		$\chi^2 = \dfrac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{\sigma_0^2}$	χ^2 Art. 4.6	$\chi^2 \geq \chi^2_{\alpha;n-1}$ if we wish to reject when the true standard deviation exceeds σ_0.	13.26	Figs. 13.35 and 13.36
					$\chi^2 \leq \chi^2_{1-\alpha;n-1}$ if we wish to reject when the true standard deviation is less than σ_0.	13.26	Figs. 13.37 and 13.38
					$\chi^2 \leq \chi^2_{1-\alpha/2;n-1}$ or $\chi^2 \geq \chi^2_{\alpha/2;n-1}$ if we wish to reject when the standard deviation departs in either direction from σ_0.	13.26	Figs. 13.33 and 13.34

Hypothesis	Notation for hypothesis	Qualifying conditions	Statistic used in test
The means of two normal distributions are equal	$\mu_x = \mu_y$	Known standard deviations σ_x, σ_y	$U = \dfrac{\bar{x} - \bar{y}}{\sqrt{\sigma_x^2/n_x + \sigma_y^2/n_y}}$
The means of two normal distributions are equal	$\mu_x = \mu_y$	Unknown standard deviations with $\sigma_x = \sigma_y$	$t = \dfrac{\bar{x} - \bar{y}}{\sqrt{\dfrac{1}{n_x} + \dfrac{1}{n_y}}\sqrt{\dfrac{\sum_{i=1}^{n_x}(x_i - \bar{x})^2 + \sum_{i=1}^{n_y}(y_i - \bar{y})^2}{n_x + n_y - 2}}}$
The means of two normal distributions are equal	$\mu_x = \mu_y$	Unknown standard deviations with σ_x and σ_y not necessarily equal	$t' = \dfrac{\bar{x} - \bar{y}}{\sqrt{s_x^2/n_x + s_y^2/n_y}}$
The variance of two normal distributions are equal	$\sigma_x^2 = \sigma_y^2$		$F = \dfrac{s_x^2}{s_y^2} = \dfrac{\sum_{i=1}^{n_x}(x_i - \bar{x})^2/(n_x - 1)}{\sum_{i=1}^{n_y}(y_i - \bar{y})^2/(n_y - 1)}$ In a two-sided test, put the larger mean square in the numerator

against the advantage in decreasing the probability of accepting the null hypothesis when it is false.

In practice, there are two major limitations to the use of OC curves. Very often, the number of observations is fixed in advance, by custom, limitation of testing equipment, or indeed the statistical analysis may be of secondary importance based on data taken for another purpose. Even in this case, a look at the OC curve is important, since it gives an idea of the type of differences you are likely to detect and hence an indication of the sensitivity of the analysis. In the second place, it often happens that the OC curve depends on parameters in which you are not interested, since the OC curve for the test of equality of two means depends on the ratio of the difference of the means to the standard deviation. However, even if only the general magnitude of the standard deviation is known, the OC curves are useful in designing experiments. The experimentalist must realize that whenever he picks a sample size he is implicitly picking an OC curve, and the more information he has available in making this decision the better. The OC curves for most of the standard significance tests are presented in this chapter.

Reference to detailed explanation	Rule of rejection	Table	Choice of sample size
Art. 4.7	$U \geq K_\alpha$ if we wish to reject when $\mu_x > \mu_y$.	13.3	Fig. 13.27 and 13.28
	$U \leq -K_\alpha$ if we wish to reject when $\mu_x < \mu_y$.	13.3	Fig. 13.27 and 13.28
	$\lvert U\rvert \geq K_{\alpha/2}$ if we wish to reject whenever the means differ.	13.3	Fig. 13.25 and 13.26
Art. 4.8	$t \geq t_{\alpha;n_x+n_y-2}$ if we wish to reject when $\mu_x > \mu_y$.	13.25	Fig. 13.31 and 13.32
	$t \leq -t_{\alpha;n_x+n_y-2}$ if we wish to reject when $\mu_x < \mu_y$.	13.25	Fig. 13.31 and 13.32
	$\lvert t\rvert \geq t_{\alpha/2;n_x+n_y-2}$ if we wish to reject whenever $\mu_x \neq \mu_y$.	13.25	Fig. 13.29 and 13.30
Art. 4.9	$t' \geq t_{\alpha;v}$ if we wish to reject when $\mu_x > \mu_y$. $t' \leq -t_{\alpha,v}$ if we wish to reject when $\mu_x < \mu_y$. $\lvert t'\rvert \geq t_{\alpha/2;v}$ when we wish to reject when $\mu_x \neq \mu_y$. where the degrees of freedom v is given by the closest integer to $v_0 = -2 + \left(\frac{s_x^2}{n_x} + \frac{s_y^2}{n_y}\right)^2/[(s_x^2/n_x)^2/(n_x+1) + (s_y^2/n_y)^2/(n_y+1)]$.	13.25 13.25 13.25	There are no results available
Art. 4.10	$F \geq F_{\alpha;n_x-1,n_y-1}$ if we wish to reject when $\sigma_x > \sigma_y$.	13.27	Fig. 13.41 and 13.42
	$F \geq F_{\alpha/2;n_x-1,n_y-1}$ if $s_x^2 > s_y^2$ and we wish to reject whenever $\sigma_x \neq \sigma_y$.	13.27	Fig. 13.39 and 13.40
	$F \geq F_{\alpha/2,n_y-1,n_x-1}$ if $s_x^2 < s_y^2$ and we wish to reject whenever $\sigma_x \neq \sigma_y$.	13.27	Fig. 13.39 and 13.40

All the tests described in this article are based on the assumption that the populations from which we draw samples are normal distributions. This assumption, which underlies a good deal of statistical technique today, is, of course, never exactly true, but has been shown to be approximately true by both empirical and theoretical studies, and the techniques derived on this assumption are adequate for most practical problems. Care should be taken, however, not to apply one-sided tests to very skew distributions.

A summary of the tests discussed in this section can be found in Tables 13.22 and 13.23.

4.3 NOTATION

The notation used in the following discussion will be the standard statistical notation found in most statistics texts. The observations $x_1, x_2, x_3, \ldots, x_n$ will be assumed to be drawn from a normal distribution with mean μ and variance σ^2.

$$\bar{x} = \frac{x_1 + x_2 + \ldots + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n}$$

is an estimate of μ, and

$$s^2 = \sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1} = \frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2}{n-1}$$

is an estimate of σ^2. The best computational form for s^2 is given by

$$s^2 = \frac{x_1^2 + x_2^2 + \ldots + x_n^2 - n\bar{x}^2}{n-1}$$

Here α is the level of significance, and K_α, $t_{\alpha;\nu}$, $\chi^2_{\alpha;\nu}$, and $F_{\alpha;\nu_1,\nu_2}$ are respectively the α percentage points of the normal distribution, the α percentage point of Student's t distribution with ν degrees of freedom, the α percentage point of the chi-square distribution with ν degrees of freedom, and the α percentage point of the F distribution with ν_1 and ν_2 degrees of freedom.

4.4 TEST OF THE HYPOTHESIS THAT THE MEAN OF A NORMAL DISTRIBUTION HAS A SPECIFIED VALUE WHEN THE STANDARD DEVIATION IS KNOWN

Notation for hypothesis	*Test statistic*
$\mu = \mu_0$	$U = \sqrt{n}\,(\bar{x} - \mu_0)/\sigma$
Rule of rejection	*Rule for choosing sample size*
$U \geq K_\alpha$ if we wish to reject when the true mean exceeds μ_0.	Select a value $\mu_1 > \mu_0$ for which we want to reject the null hypothesis with high probability, and calculate $d = (\mu_1 - \mu_0)/\sigma$, and select n from the OC curve of Fig. 13.27 or 13.28.
$U \leq -K_\alpha$ if we wish to reject when the true mean is less than μ_0.	Choose a value $\mu_1 < \mu_0$ which we want to reject and enter Fig. 13.27 or 13.28 with $d = (\mu_0 - \mu_1)/\sigma$.
$\|U\| \geq K_{\alpha/2}$ if we wish to reject when the true mean departs from μ_0 in either direction.	Select a value Δ that is a departure from μ_0 we want to reject with high probability and enter Fig. 13.25 or 13.26 with $d = \|\Delta\|/\sigma$.

TABLE 13.24 PERCENTAGE POINTS OF THE NORMAL DISTRIBUTION

Level of significance	*For one-sided tests*	*For two-sided tests*
$\alpha = 0.05$	$K_{0.05} = 1.645$	$K_{0.025} = 1.960$
$\alpha = 0.01$	$K_{0.01} = 2.326$	$K_{0.005} = 2.576$

4.4.1 Example. A manufacturer produces a special alloy steel with an average tensile strength of 125,800 psi. A change in the composition of the alloy is said to increase the breaking strength. A sample of 20 items of the new material is tested, and the average tensile strength is found to be 127,000.

The standard deviation of the tensile strength is known to be 300 psi. To decide whether to adopt the new alloy, we test the hypothesis that the breaking strength is unchanged, i.e., that the new value could have arisen by chance from a population with true mean of 125,800. The statistic U is calculated:

$$U = \frac{\sqrt{n}\,(\bar{x} - \mu_0)}{\sigma} = \frac{\sqrt{20}\,(127{,}000 - 125{,}800)}{300} = 17.888$$

Since we are interested in rejecting the hypothesis that the breaking strength is unchanged only if it is increased, we use a one-tailed test. As our observed value of U exceeds the critical value for the 1% level $K_{.01} = 2.326$, we reject the hypothesis and conclude that the new alloy produces greater tensile strength than the old.

In this case, we based our decision on a sample of 20 observations; the sample size was picked arbitrarily. However, the operating characteristic curves of the U test in Fig. 13.28 (for 0.01 level of significance) provide an objective basis for the selection of a sample size. These curves give the probability of accepting the hypothesis as a function of the difference between the true mean and the hypothesized one, in σ units, e.g., for a sample size of 20 the probability of accepting is about 0.10 for a difference of $0.80\sigma = 240$. Ordinarily, we would use this graph before running the experiment and select the sample size which will have a high probability of detecting a difference that is important from a practical point of view.

FIG. 13.25 OPERATING CHARACTERISTICS OF THE TWO-SIDED NORMAL TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.05.

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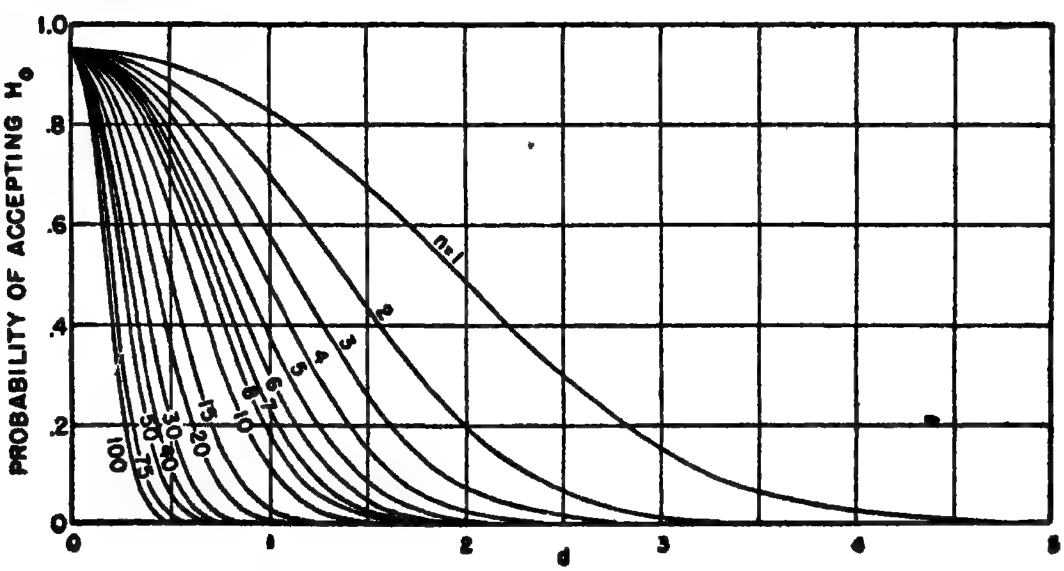


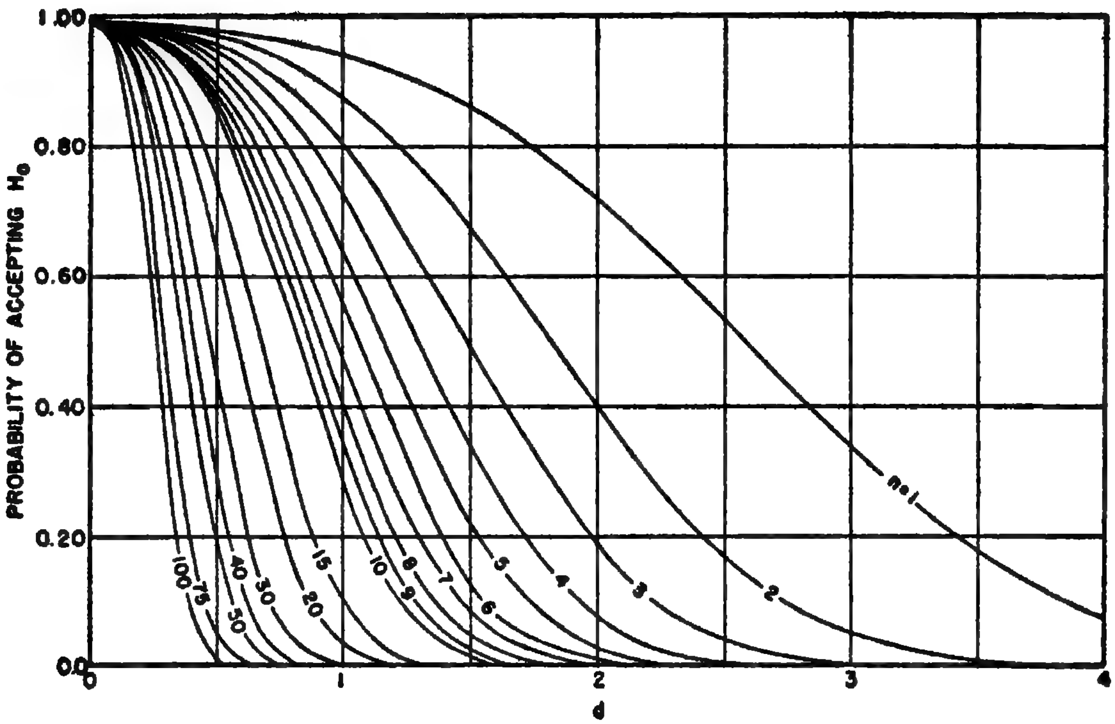
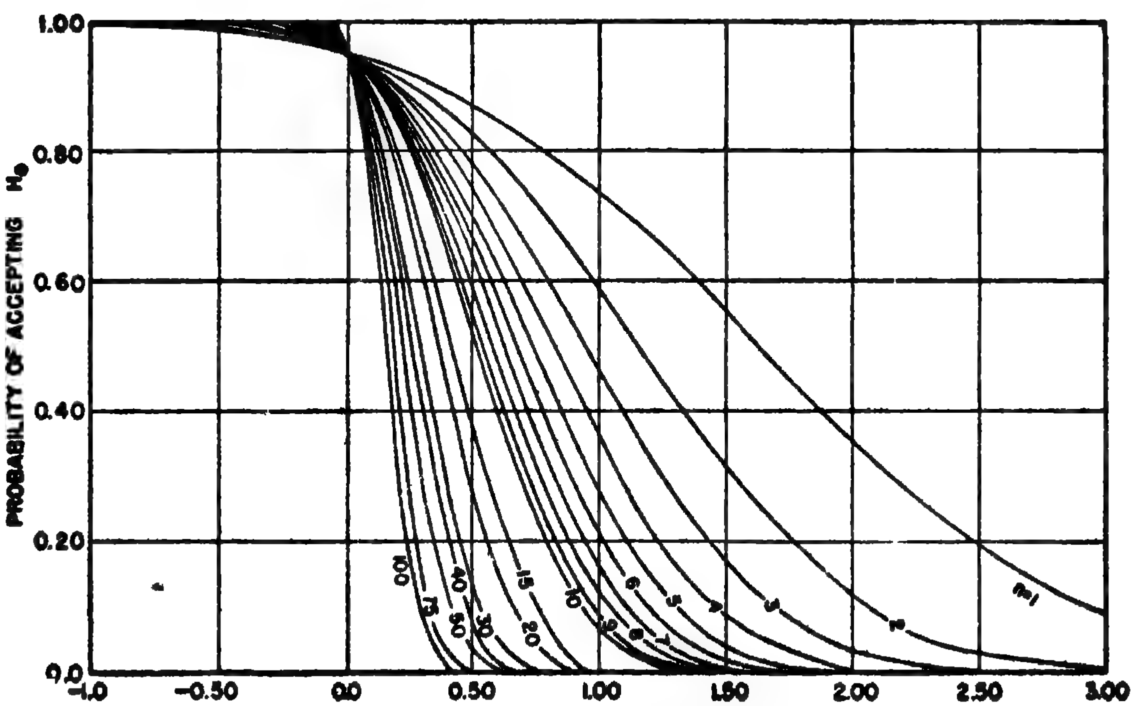


FIG. 13.26 OPERATING CHARACTERISTICS OF THE TWO-SIDED NORMAL TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.01.

FIG. 13.27 OPERATING CHARACTERISTICS OF THE ONE-SIDED NORMAL TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.05.



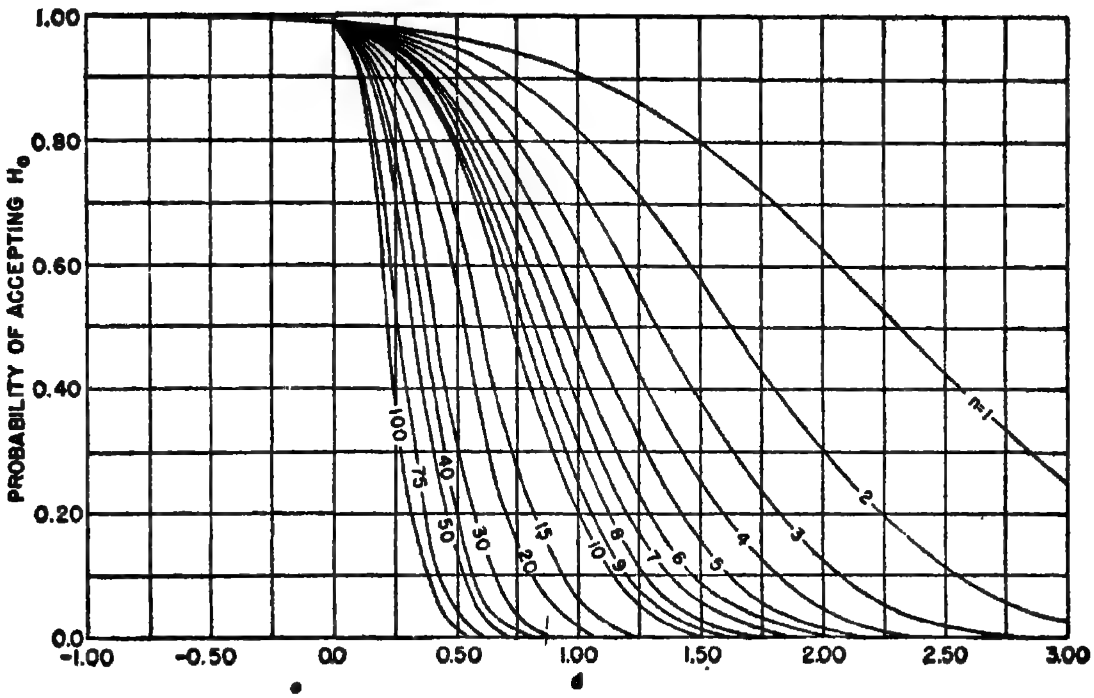


FIG. **13.28** OPERATING CHARACTERISTICS OF THE ONE-SIDED NORMAL TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.01.

4.5 TEST OF THE HYPOTHESIS THAT THE MEAN OF A NORMAL DISTRIBUTION HAS A SPECIFIED VALUE WHEN THE STANDARD DEVIATION IS UNKNOWN

Notation for hypothesis	*Test statistic*
$\mu = \mu_0$	$t = \sqrt{n}\,(\bar{x} - \mu_0)/s$
Rule of rejection	*Rule for choosing sample sizes*
$t \geq t_{\alpha;n-1}$ if we wish to reject when the true mean exceeds μ_0.	Choose a value of $d = (\mu_1 - \mu_0)/\sigma$★ for which we wish to reject the null hypothesis with high probability and enter Fig. 13.31 or 13.32 to find the necessary sample size.
$t \leq -t_{\alpha;n-1}$ if we wish to reject when the true mean is less than μ_0.	Choose a value of $d = (\mu_0 - \mu_1)/\sigma$ for which we wish to reject the null hypothesis with high probability and enter Fig. 13.31 or 13.32 to find the necessary sample size.
$\lvert t\rvert \geq t_{\alpha/2;n-1}$ if we wish to reject when the true mean differs from μ_0 in either direction.	Choose a value of $d = \left\lvert\frac{\mu_1 - \mu_0}{\sigma}\right\rvert$ for which we wish to reject the null hypothesis with high probability and enter Fig. 13.29 or 13.30 to find the necessary sample size.

★ The operating characteristic curve of the t test, unlike the U test, depends on the ratio of $\mu_0 - \mu_1$ to σ, although the test procedure is independent of σ, as is the level of significance. Usually a rough idea of the magnitude of σ is sufficient for choosing the necessary sample size.

4.5.1 Example. In the manufacture of a food product, the label states that the box contains 10 lb. The boxes are filled by machine, and it is of interest to determine whether or not the machine is set properly. Previous experience has indicated that the standard deviation is approximately 0.05 lb, although this is not known precisely. The company feels that the present setting is un-

TABLE 13.25 PERCENTAGE POINTS OF THE t DISTRIBUTION*

Table of $t_{\alpha;\nu}$—the 100 α percentage point of the t distribution for ν degrees of freedom

ν \ α	.10	.050	.025	.010	.005	α / ν
1	3.078	6.314	12.706	31.821	63.657	1
2	1.886	2.920	4.303	6.965	9.925	2
3	1.638	2.353	3.182	4.541	5.841	3
4	1.533	2.132	2.776	3.747	4.604	4
5	1.476	2.015	2.571	3.365	4.032	5
6	1.440	1.943	2.447	3.143	3.707	6
7	1.415	1.895	2.365	2.998	3.499	7
8	1.397	1.860	2.306	2.896	3.355	8
9	1.383	1.833	2.262	2.821	3.250	9
10	1.372	1.812	2.228	2.764	3.169	10
11	1.363	1.796	2.201	2.718	3.106	11
12	1.356	1.782	2.179	2.681	3.055	12
13	1.350	1.771	2.160	2.650	3.012	13
14	1.345	1.761	2.145	2.624	2.977	14
15	1.341	1.753	2.131	2.602	2.947	15
16	1.337	1.746	2.120	2.583	2.921	16
17	1.333	1.740	2.110	2.567	2.898	17
18	1.330	1.734	2.101	2.552	2.878	18
19	1.328	1.729	2.093	2.539	2.861	19
20	1.325	1.725	2.086	2.528	2.845	20
21	1.323	1.721	2.080	2.518	2.831	21
22	1.321	1.717	2.074	2.508	2.819	22
23	1.319	1.714	2.069	2.500	2.807	23
24	1.318	1.711	2.064	2.492	2.797	24
25	1.316	1.708	2.060	2.485	2.787	25
26	1.315	1.706	2.056	2.479	2.779	26
27	1.314	1.703	2.052	2.473	2.771	27
28	1.313	1.701	2.048	2.467	2.763	28
29	1.311	1.699	2.045	2.462	2.756	29
Inf.	1.282	1.645	1.960	2.326	2.576	Inf.

* Reproduced from J. E. Freund, *Modern Elementary Statistics* (New York: Prentice-Hall, Inc., 1952), Table II, p. 390, Control Values of t. This table is abridged from Table IV of R. A. Fisher, *Statistical Methods for Research Workers*, published by Oliver & Boyd Ltd., Edinburgh, by permission of the author and publishers.

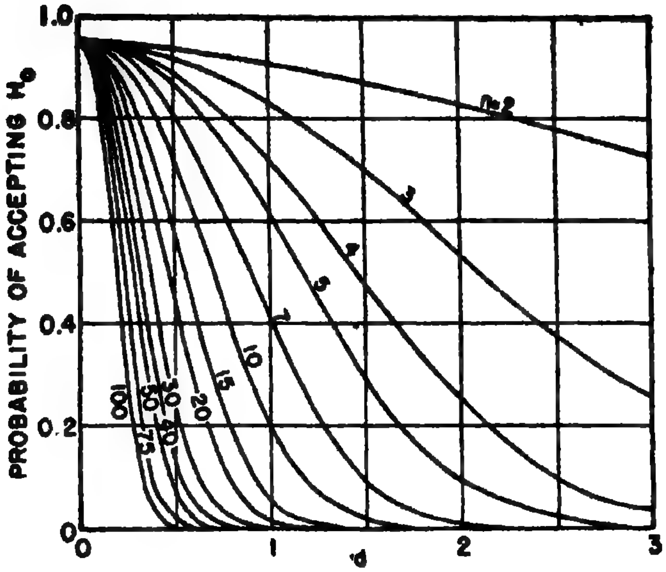


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FIG. 13.29 OPERATING CHARACTERISTICS OF THE TWO-SIDED t TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.05.

satisfactory if the machine fills the boxes so that the mean weight differs from 10 lb by more than 0.1 lb. From Fig. 13.29 and $d = 0.1/0.05 = 2$, a sample size of 6 is sufficient to insure rejection with probability 0.95 if the mean weight differs from 10 lb by more than 0.1 lb. The data are: 9.99 lb, 9.99 lb, 10.00 lb, 10.11 lb, 10.09 lb, 9.95 lb.

$$\bar{x} = 10.021667\star$$

$$s^2 = \frac{\sum (x_i - \bar{x})^2}{n-1} = \frac{\sum x_i^2 - n\bar{x}^2}{n-1} = \frac{602.6229 - 602.6029}{5} = 0.0040$$

$$s = 0.0632$$

$$\frac{\sqrt{n}(\bar{x} - 10)}{s} = \frac{\sqrt{6}(10.0217 - 10)}{0.0632} = 0.84$$

$$t_{.025;5} = 2.571 \qquad \text{for 5 degrees of freedom}$$

Thus $|t| \leq t_{.025;5}$ so that it is unnecessary to change the machine setting.

★ It is important to compute $\bar{x}$ to more places than appears necessary for the significance of the final result. The reason becomes clear upon looking at the calculation of s^2 where a subtraction operation is involved.

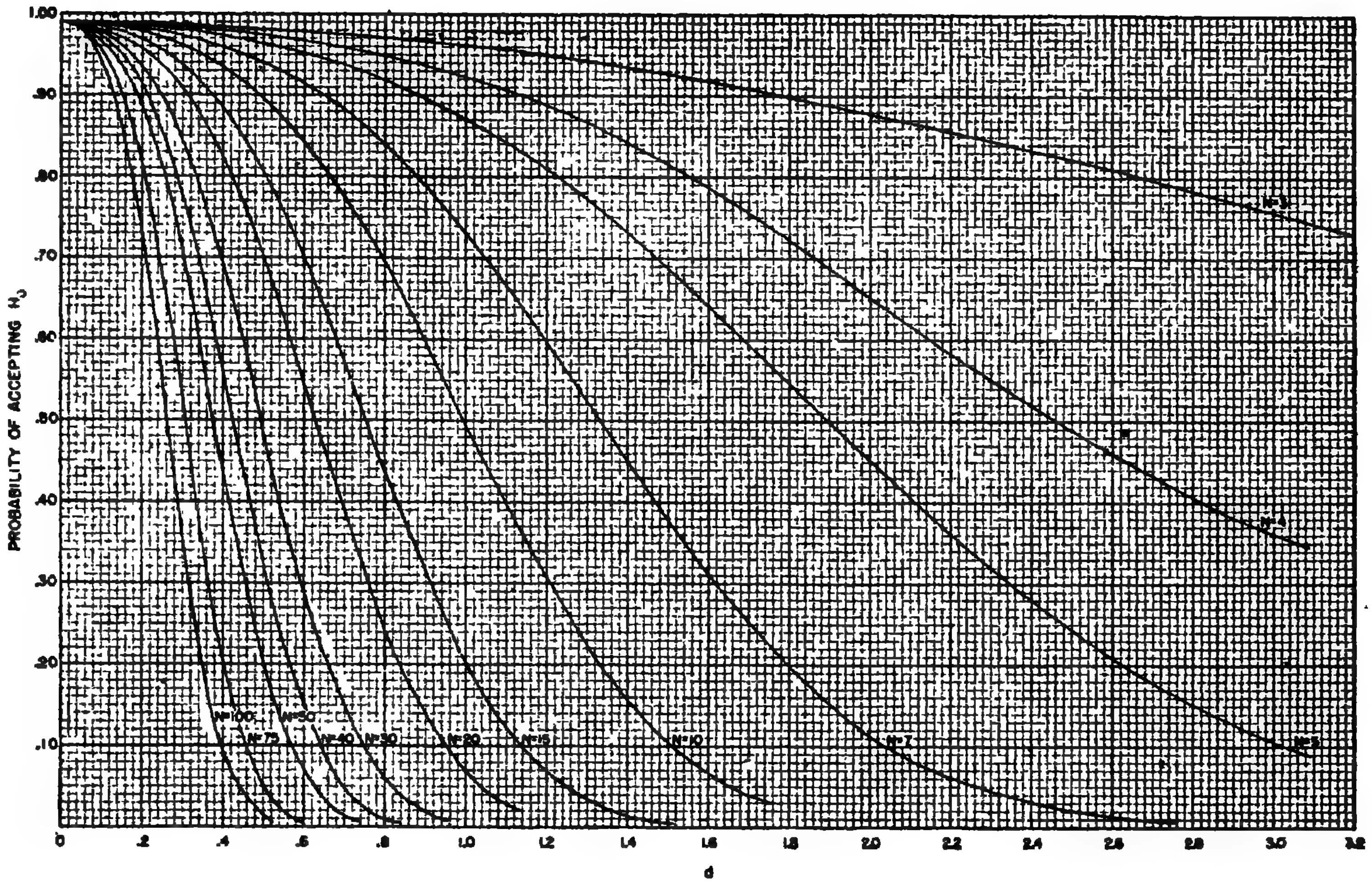


FIG. **13.30** OPERATING CHARACTERISTICS OF THE TWO-SIDED t TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.01.

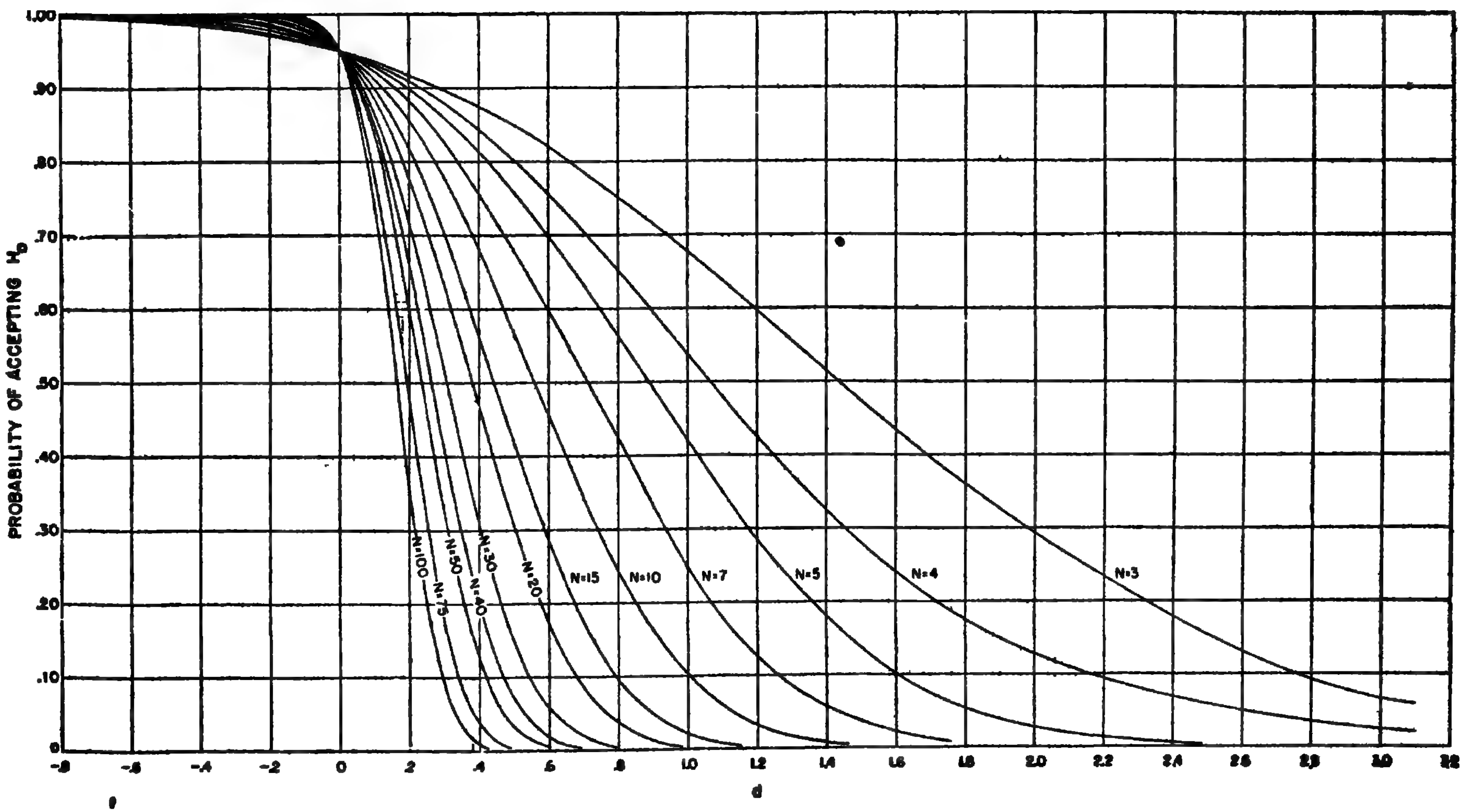


FIG. 13.31 OPERATING CHARACTERISTICS OF THE ONE-SIDED t TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.05.

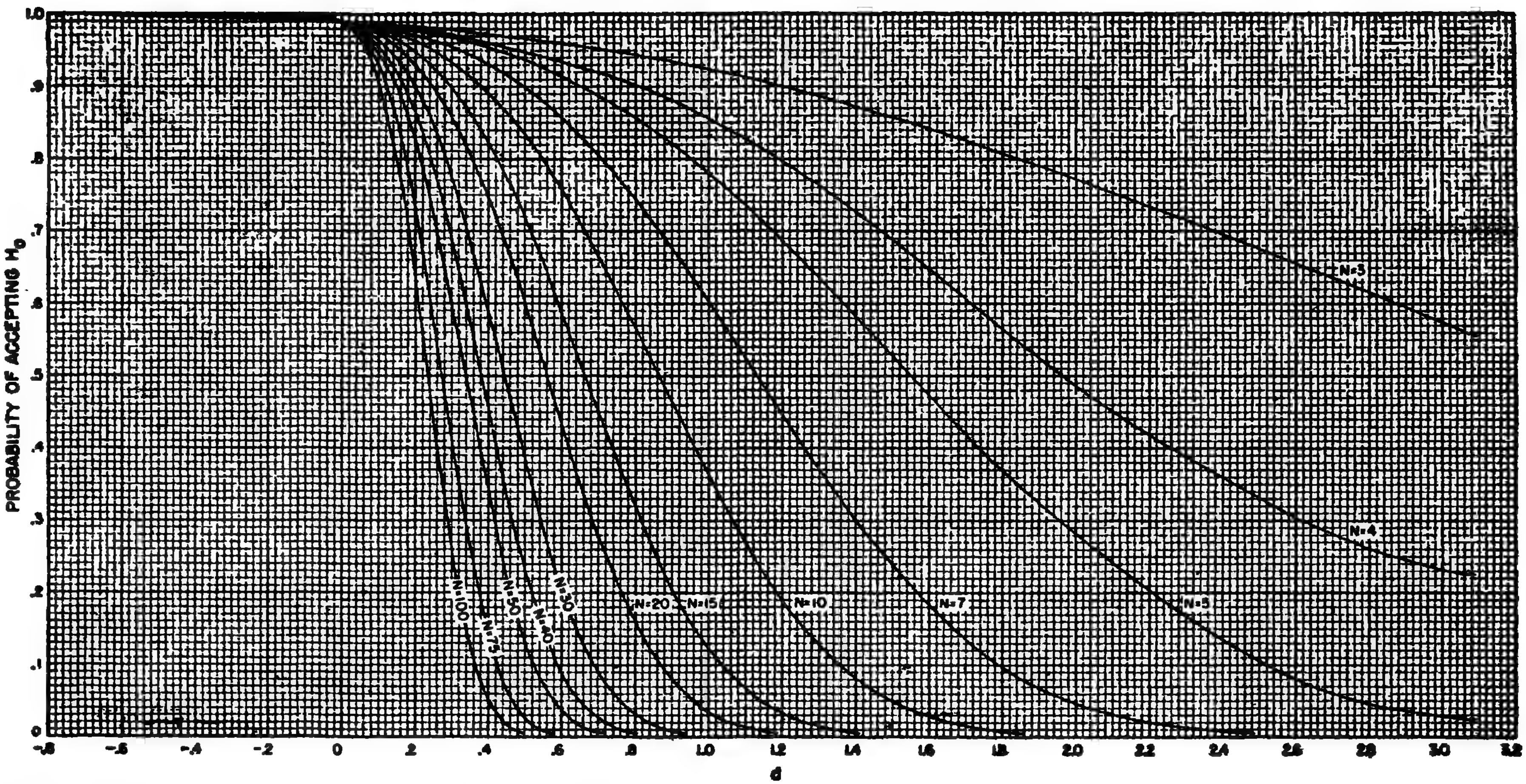


FIG. 13.32 OPERATING CHARACTERISTICS OF THE ONE-SIDED t TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.01.

4.6 TEST OF HYPOTHESIS THAT THE VARIANCE OF A NORMAL DISTRIBUTION HAS A SPECIFIED VALUE

Notation for hypothesis	*Test statistic*
$= \sigma_0$	$\chi^2 = (n-1)s^2/\sigma_0^2$
Rule of rejection	*Rule for choosing sample sizes*
$\chi^2 \geq \chi^2_{\alpha;n-1}$ if we wish to reject when the true standard deviation exceeds σ_0.	Select a value $\sigma_1 > \sigma_0$ for which we wish to reject the null hypothesis with high probability. Calculate $\lambda = \sigma_1/\sigma_0$ and enter Fig. 13.35 or 13.36 to find the required sample size.
$\chi^2 \leq \chi^2_{1-\alpha;n-1}$ if we wish to reject when the true standard deviation is less than σ_0.	Select a value $\sigma_1 < \sigma_0$ for which we wish to reject the null hypothesis with high probability. Calculate $\lambda = \sigma_1/\sigma_0$ and enter Fig. 13.37 or 13.38 to find the required sample size.
$\chi^2 \geq \chi^2_{\alpha/2;n-1}$ or $\chi^2 \leq \chi^2_{1-\alpha/2;n-1}$ if we wish to reject when the true standard deviation differs from σ_0 in either direction.	Select a value of the relative error σ_1/σ_0 for which we wish to reject the null hypothesis with high probability. Enter Fig. 13.33 or 13.34 to find the required sample size.

Percentage points of the chi-square distribution can be found in Table 13.26.

4.6.1 Example. The standard deviation of a dimension of standard product is $\sigma = 0.1225$ in. A new product is under consideration and will be adopted if the variability of this dimension is not larger. The decision about variability will be based on a sample of items of the new product. If σ is as large as 0.2450 in., we want to be quite sure to reject. From Fig. 13.36 it appears that a sample size of 25 will give a probability of acceptance of 0.01 for $\lambda = 0.2450/0.1225 = 2$ if we make the test at the 1% level. A sample of 25 items is drawn and s^2 is found to be 0.0384. Hence $\chi^2 = (n-1)s^2/\sigma_0^2 = 61.4$, which exceeds $\chi^2_{.01;24} = 43.0$. The new product is not adopted.

TABLE 13.26 PERCENTAGE POINTS

Table of $\chi^2_{\alpha;\nu}$—the 100 α percentage point of

$\chi^2_{\alpha;\nu}$

ν \ α	.995	.99	.98	.975	.95	.90	.80	.75	.70	.50
1	$.0^4393$	$.0^3157$	$.0^3628$	$.0^3982$	.00393	.0158	.0642	.102	.148	.455
2	.0100	.0201	.0404	.0506	.103	.211	.446	.575	.713	1.386
3	.0717	.115	.185	.216	.352	.584	1.005	1.213	1.424	2.366
4	.207	.297	.429	.484	.711	1.064	1.649	1.923	2.195	3.357
5	.412	.554	.752	.831	1.145	1.610	2.343	2.675	3.000	4.351
6	.676	.872	1.134	1.237	1.635	2.204	3.070	3.455	3.828	5.348
7	.989	1.239	1.564	1.690	2.167	2.833	3.822	4.255	4.671	6.346
8	1.344	1.646	2.032	2.180	2.733	3.490	4.594	5.071	5.527	7.344
9	1.735	2.088	2.532	2.700	3.325	4.168	5.380	5.899	6.393	8.343
10	2.156	2.558	3.059	3.247	3.940	4.865	6.179	6.737	7.267	9.342
11	2.603	3.053	3.609	3.816	4.575	5.578	6.989	7.584	8.148	10.341
12	3.074	3.571	4.178	4.404	5.226	6.304	7.807	8.438	9.034	11.340
13	3.565	4.107	4.765	5.009	5.892	7.042	8.634	9.299	9.926	12.340
14	4.075	4.660	5.368	5.629	6.571	7.790	9.467	10.165	10.821	13.339
15	4.601	5.229	5.985	6.262	7.261	8.547	10.307	11.036	11.721	14.339
16	5.142	5.812	6.614	6.908	7.962	9.312	11.152	11.912	12.624	15.338
17	5.697	6.408	7.255	7.564	8.672	10.085	12.002	12.792	13.531	16.338
18	6.265	7.015	7.906	8.231	9.390	10.865	12.857	13.675	14.440	17.338
19	6.844	7.633	8.567	8.907	10.117	11.651	13.716	14.562	15.352	18.338
20	7.434	8.260	9.237	9.591	10.851	12.443	14.578	15.452	16.266	19.337
21	8.034	8.897	9.915	10.283	11.591	13.240	15.445	16.344	17.182	20.337
22	8.643	9.542	10.600	10.982	12.338	14.041	16.314	17.240	18.101	21.337
23	9.260	10.196	11.293	11.688	13.091	14.848	17.187	18.137	19.021	22.337
24	9.886	10.856	11.992	12.401	13.848	15.659	18.062	19.037	19.943	23.337
25	10.520	11.524	12.697	13.120	14.611	16.473	18.940	19.939	20.867	24.337
26	11.160	12.198	13.409	13.844	15.379	17.292	19.820	20.843	21.792	25.336
27	11.808	12.879	14.125	14.573	16.151	18.114	20.703	21.749	22.719	26.336
28	12.461	13.565	14.847	15.308	16.928	18.939	21.588	22.657	23.647	27.336
29	13.121	14.256	15.574	16.047	17.708	19.768	22.475	23.567	24.577	28.336
30	13.787	14.953	16.306	16.791	18.493	20.599	23.364	24.478	25.508	29.336

For values of $\nu > 30$, approximate values for χ^2 may be obtained from the expression $\nu\left[1 - \frac{2}{9\nu} \pm \frac{x}{\sigma}\sqrt{\frac{2}{9\nu}}\right]^3$, where $\frac{x}{\sigma}$ is the normal deviate cutting off the corresponding tails of a normal distribution. If $\frac{x}{\sigma}$ is taken at the 0.02 level, so that 0.01 of the normal distribution is in each tail, the expression yields χ^2 at the 0.99 and 0.01

OF THE χ^2 DISTRIBUTION

the χ^2 distribution for ν degrees of freedom

.30	.25	.20	.10	.05	.025	.02	.01	.005	.001	α / ν
1.074	1.323	1.642	2.706	3.841	5.024	5.412	6.635	7.879	10.827	1
2.408	2.773	3.219	4.605	5.991	7.378	7.824	9.210	10.597	13.815	2
3.665	4.108	4.642	6.251	7.815	9.348	9.837	11.345	12.838	16.268	3
4.878	5.385	5.989	7.779	9.488	11.143	11.668	13.277	14.860	18.465	4
6.064	6.626	7.289	9.236	11.070	12.832	13.388	15.086	16.750	20.517	5
7.231	7.841	8.558	10.645	12.592	14.449	15.033	16.812	18.548	22.457	6
8.383	9.037	9.803	12.017	14.067	16.013	16.622	18.475	20.278	24.322	7
9.524	10.219	11.030	13.362	15.507	17.535	18.168	20.090	21.955	26.125	8
10.656	11.389	12.242	14.684	16.919	19.023	19.679	21.666	23.589	27.877	9
11.781	12.549	13.442	15.987	18.307	20.483	21.161	23.209	25.188	29.588	10
12.899	13.701	14.631	17.275	19.675	21.920	22.618	24.725	26.757	31.264	11
14.011	14.845	15.812	18.549	21.026	23.337	24.054	26.217	28.300	32.909	12
15.119	15.984	16.985	19.812	22.362	24.736	25.472	27.688	29.819	34.528	13
16.222	17.117	18.151	21.064	23.685	26.119	26.873	29.141	31.319	36.123	14
17.322	18.245	19.311	22.307	24.996	27.488	28.259	30.578	32.801	37.697	15
18.418	19.369	20.465	23.542	26.296	28.845	29.633	32.000	34.267	39.252	16
19.511	20.489	21.615	24.769	27.587	30.191	30.995	33.409	35.718	40.790	17
20.601	21.605	22.760	25.989	28.869	31.526	32.346	34.805	37.156	42.312	18
21.689	22.718	23.900	27.204	30.144	32.852	33.687	36.191	38.582	43.820	19
22.775	23.828	25.038	28.412	31.410	34.170	35.020	37.566	39.997	45.315	20
23.858	24.935	26.171	29.615	32.671	35.479	36.343	38.932	41.401	46.797	21
24.939	26.039	27.301	30.813	33.924	36.781	37.659	40.289	42.796	48.268	22
26.018	27.141	28.429	32.007	35.172	38.076	38.968	41.638	44.181	49.728	23
27.096	28.241	29.553	33.196	36.415	39.364	40.270	42.980	45.558	51.179	24
28.172	29.339	30.675	34.382	37.652	40.646	41.566	44.314	46.928	52.620	25
29.246	30.434	31.795	35.563	38.885	41.923	42.856	45.642	48.290	54.052	26
30.319	31.528	32.912	36.741	40.113	43.194	44.140	46.963	49.645	55.476	27
31.391	32.620	34.027	37.916	41.337	44.461	45.419	48.278	50.993	56.893	28
32.461	33.711	35.139	39.087	42.557	45.722	46.693	49.588	52.336	58.302	29
33.530	34.800	36.250	40.256	43.773	46.979	47.962	50.892	53.672	59.703	30

points. For very large values of ν, it is sufficiently accurate to compute $\sqrt{2\chi^2}$, the distribution of which is approximately normal around a mean of $\sqrt{2\nu - 1}$ and with a standard deviation of 1.

This table is taken by consent from *Statistical Tables for Biological, Agricultural, and Medical Research*, by R. A. Fisher and F. Yates, published by Oliver and Boyd, Edinburgh, and from *Biometrika*, Vol. XXXII, Part II, October 1941, pp. 187-191, "Table of Percentage Points of the χ^2 Distribution," by Catherine M. Thompson. Reproduced in Croxton *Elementary Statistics with Applications in Medicine*, Appendix VI, pp. 328-329, Values of χ^2.

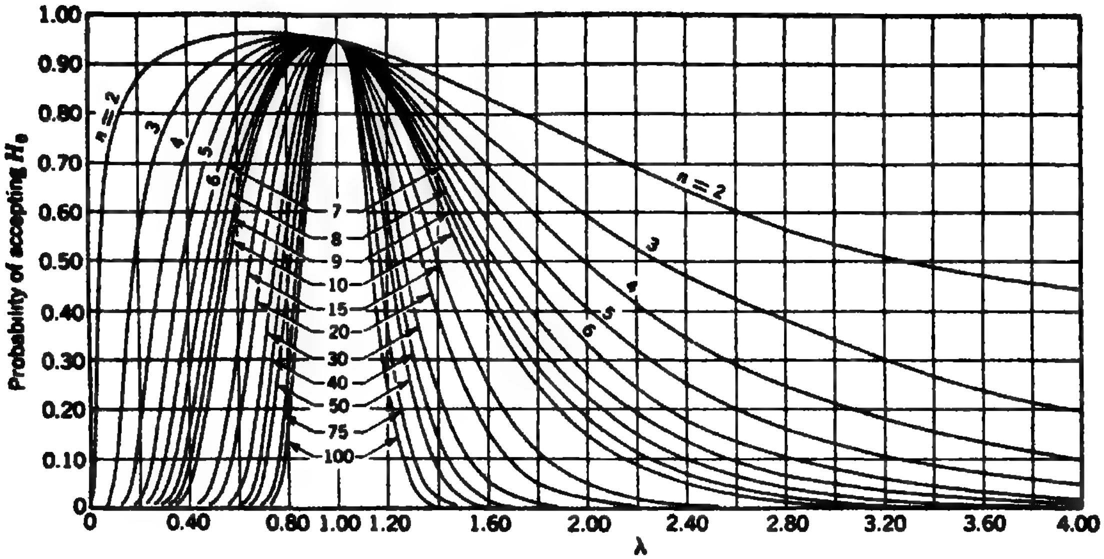
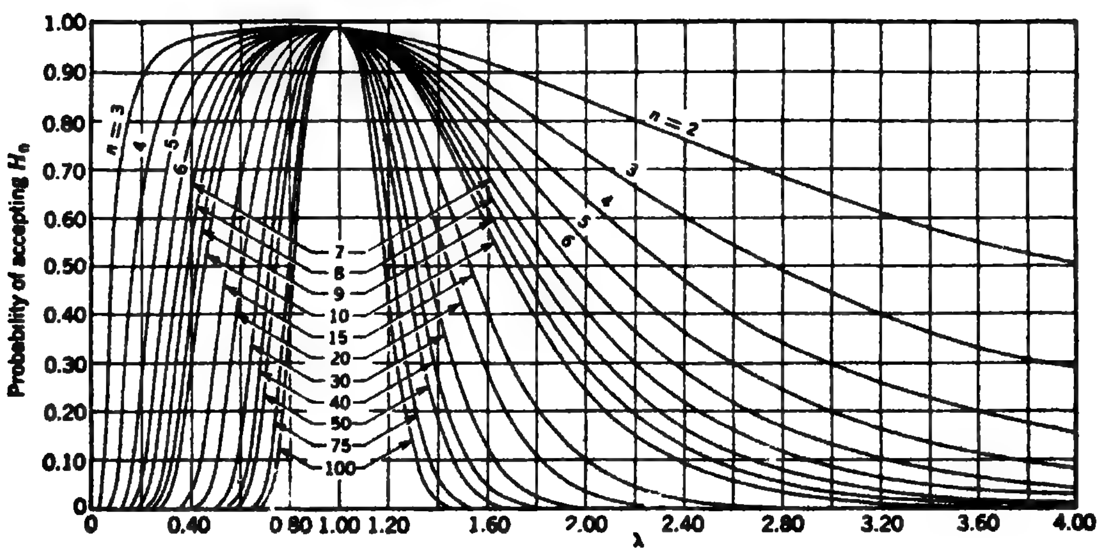


FIG. **13.33** OPERATING CHARACTERISTICS OF THE TWO-SIDED CHI-SQUARE TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.05.

FIG. **13.34** OPERATING CHARACTERISTICS OF THE TWO-SIDED CHI-SQUARE TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.01.



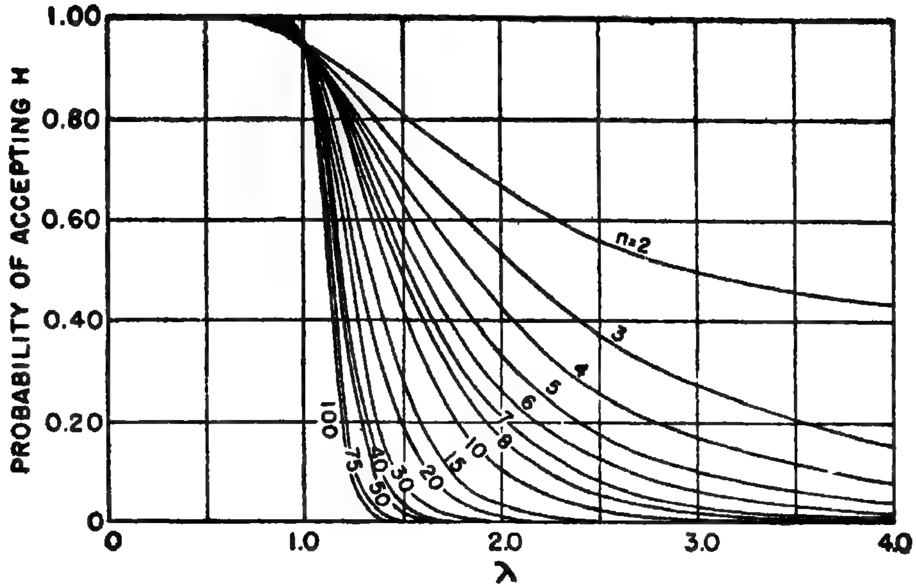


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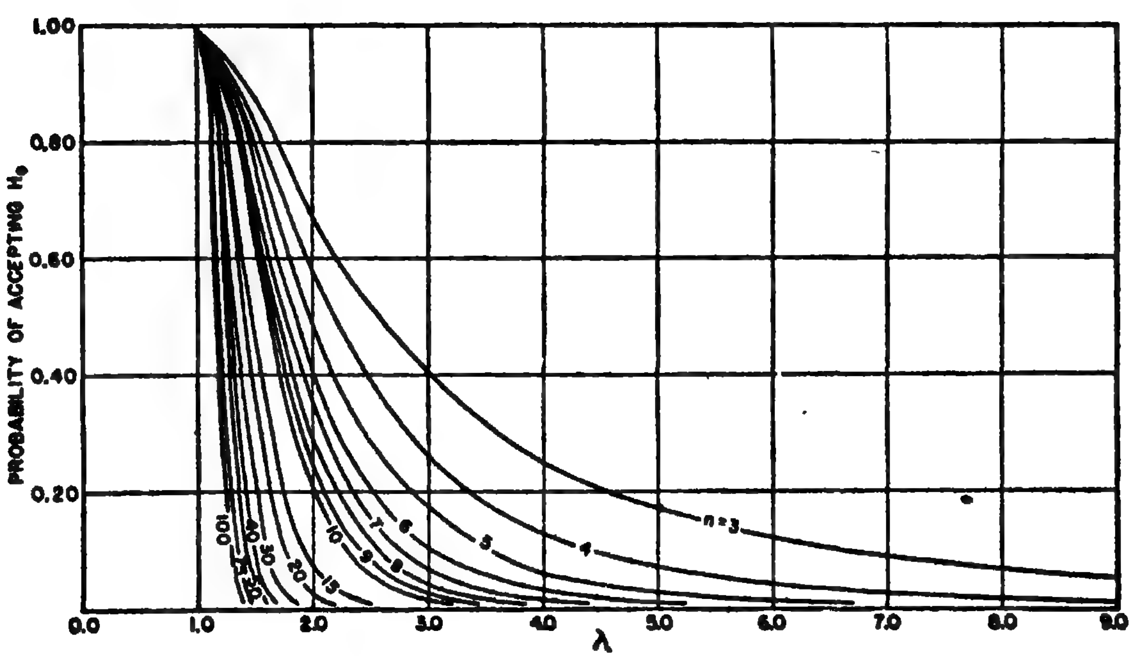
FIG. 13.35 OPERATING CHARACTERISTICS OF THE ONE-SIDED (UPPER TAIL) CHI-SQUARE TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.05.

FIG. 13.36 OPERATING CHARACTERISTICS OF THE ONE-SIDED (UPPER TAIL) CHI-SQUARE TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.01.



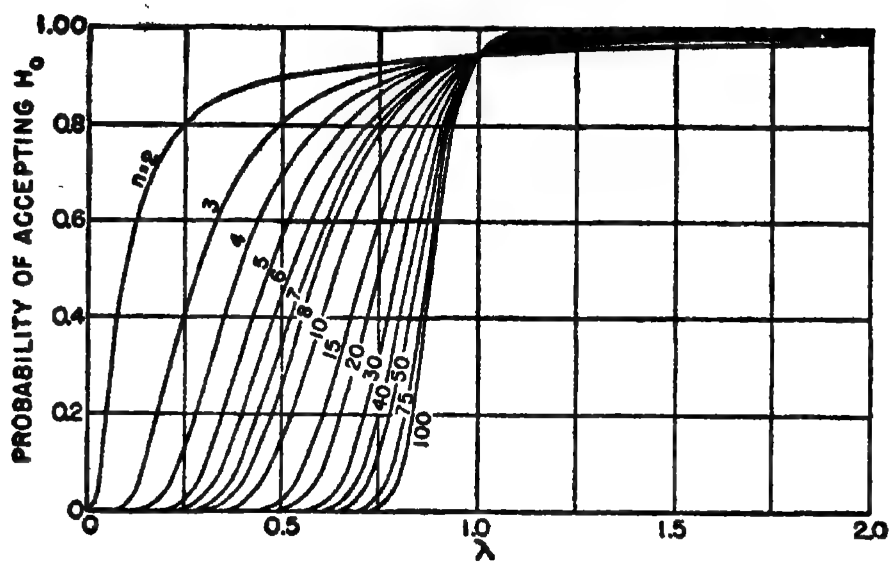


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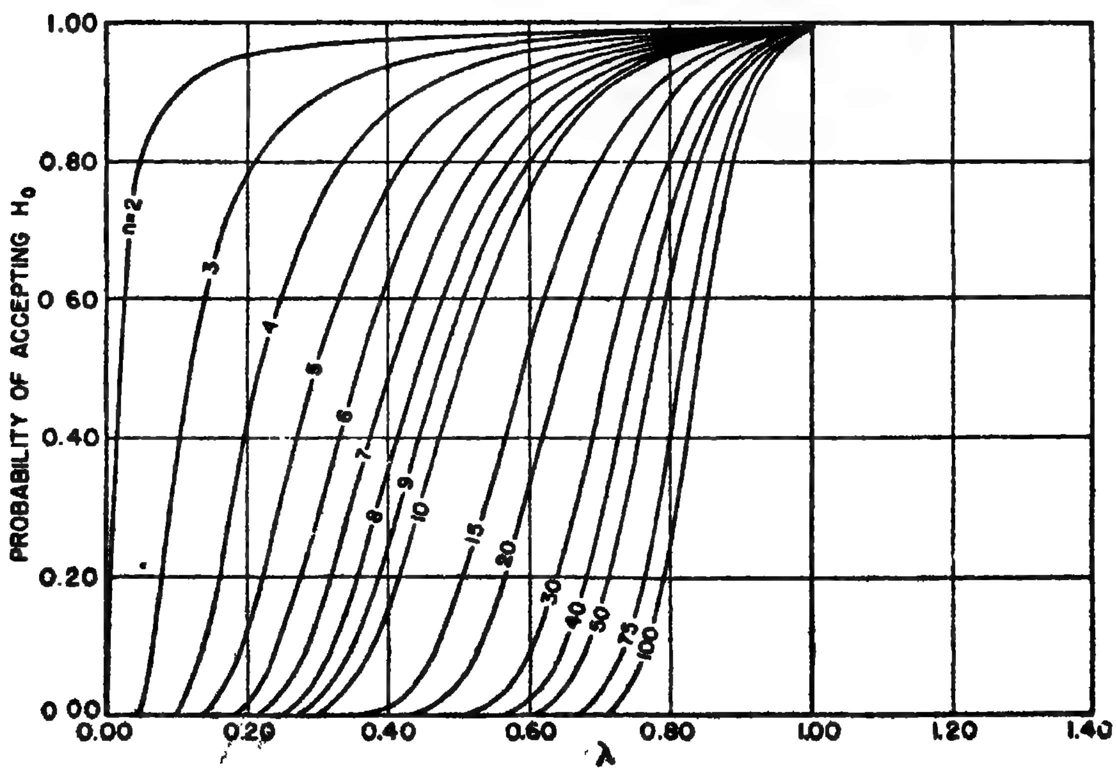
FIG. 13.37 OPERATING CHARACTERISTICS OF THE ONE-SIDED (LOWER TAIL) CHI-SQUARE TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.05.

FIG. 13.38 OPERATING CHARACTERISTICS OF THE ONE-SIDED (LOWER TAIL) CHI-SQUARE TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.01.



4.7 TEST OF THE HYPOTHESIS THAT THE MEANS OF TWO NORMAL DISTRIBUTIONS ARE EQUAL WHEN BOTH STANDARD DEVIATIONS ARE KNOWN

Notation for hypothesis	*Test statistic*
$= \mu_y$	$U = (\bar{x} - \bar{y})/\sqrt{\sigma_x^2/n_x + \sigma_y^2/n_y}$
Rule of rejection	*Rule for choosing sample sizes, assuming* $n_x = n_y = n$
$U \geq K_\alpha$ if we wish to reject when $\mu_x > \mu_y$.	Select a value $\mu_x - \mu_y > 0$ for which we want to reject the null hypothesis with high probability. Calculate★ $d = (\mu_x - \mu_y)/\sqrt{\sigma_x^2 + \sigma_y^2}$ and select n from the OC curve of Fig. 13.27 or 13.28.
$U \leq -K_\alpha$ if we wish to reject when $\mu_x < \mu_y$.	Select a value $\mu_x - \mu_y < 0$ for which we want to reject the null hypothesis with high probability. Calculate★ $d = (\mu_y - \mu_x)/\sqrt{\sigma_x^2 + \sigma_y^2}$ and select n from the OC curve of Fig. 13.27 or 13.28.
$\lvert U\rvert \geq K_{\alpha/2}$ if we wish to reject when the true difference in means is either positive or negative.	Select a value $\lvert\mu_x - \mu_y\rvert > 0$ for which we want to reject the null hypothesis with high probability. Calculate★ $d = \left\lvert\dfrac{\mu_x - \mu_y}{\sqrt{\ }}\right.$ and select n from the OC curve of Fig. 13.25 or 13.26.

★ In order to find the required sample size for the OC curves given, it is necessary to choose $n = n_x = n_y$. However, if n_x and n_y are fixed in advance, $n_x \neq n_y$, the resulting protection using the above rule can be obtained by entering the curves using d and $n = (\sigma_x^2 + \sigma_y^2)/[(\sigma_x^2/n_x) + (\sigma_y^2/n_y)]$.

TABLE 13.24 PERCENTAGE POINTS OF THE NORMAL DISTRIBUTION

Level of significance	*For one-sided tests*	*For two-sided tests*
$\alpha = 0.05$	$K_{.05} = 1.645$	$K_{.025} = 1.960$
$\alpha = 0.01$	$K_{.01} = 2.326$	$K_{.005} = 2.576$

Example. There is evidence that surface finish has an effect on the endurance limit (reversed bending) of steel. An experiment is performed on 0.4% carbon steel, using both unpolished and polished smooth-turned specimens. The finish on the smooth-turned polished specimens was obtained by polishing with No. 0 and 00 emery cloth.

For 0.4% carbon steel, it has been estimated that an average increase in the endurance limit of approximately 7500 psi should be detected on the polished specimens. Furthermore, polishing should not have any effect on the standard deviation of the endurance limit, which is known from the performance of numerous endurance limit experiments to be 4000 psi. From Fig. 13.28 (1% level of significance) with $d = 7500/\sqrt{(4000)^2 + (4000)^2} = 1.33$, we find that about eight observations on each group of specimens are required to

have a probability of 0.9 of detecting a difference as large as 7500 psi. The data is as follows:

Endurance limit for polished 0.4% carbon steel (x)	Endurance limit for unpolished 0.4% carbon steel (y)
86,500	82,600
91,900	82,400
89,400	81,700
84,000	79,500
89,900	79,400
78,700	69,800
87,500	79,900
83,100	83,400
$\bar{x} = 86{,}375$	$\bar{y} = 79{,}838$

$$U = \frac{6537}{\sqrt{(4000)^2/8 + (4000)^2/8}} = 3.27; \qquad K_{.01} = 2.326$$

Hence we reject the hypothesis at the 1% significance level that surface polish has no effect on the endurance limit, and conclude that polished 0.4% carbon steel specimens have a higher mean endurance limit than unpolished ones.

4.8 TEST OF THE HYPOTHESIS THAT THE MEANS OF TWO NORMAL DISTRIBUTIONS ARE EQUAL ASSUMING THAT THE STANDARD DEVIATIONS ARE UNKNOWN BUT EQUAL*; TWO-SAMPLE t TEST

Notation for the hypothesis	*Test statistic*
	$t = \dfrac{\bar{x} -}{\sqrt{\dfrac{1}{n_x} + \dfrac{1}{n_y}}\sqrt{\dfrac{\sum (x_i - \bar{x})^2 + \sum (y_i - \bar{y})^2}{(n_x + n_y - 2)}}}$
Rule of rejection	*Rule for choosing sample size assuming* $n_x = n_y = n$.
$t \geq t_{\alpha;n_x+n_y-2}$ if we wish to reject when $\mu_x > \mu_y$.	The OC curve depends on $d = (\mu_x - \mu_y)/2\sigma$. Estimate that value of d for which we want to be sure to reject the hypothesis and pick n' from Fig. 13.31 or 13.32. The required sample size is $(n' + 1)/2$.
$t \leq -t_{\alpha;n_x+n_y-2}$ if we wish to reject when $\mu_x < \mu_y$.	Estimate the $d = (\mu_y - \mu_x)/2\sigma$ for which we want to be sure to reject, and pick n' from Fig. 13.31 or 13.32. The required sample size is $(n' + 1)/2$.
$\lvert t \rvert \geq t_{\alpha/2;n_x+n_y-2}$ if we wish to reject whenever μ_x is not equal to μ_y.	Estimate the $d = \lvert(\mu_x - \mu_y)/2\sigma\rvert$ for which we want to be sure to reject, and pick n' from Fig. 13.29 or 13.30. The required sample size is $(n' + 1)/2$.

Example. A manufacturer of electric irons produces these items in two plants. Both plants have the same suppliers of small parts. A saving can be made by purchasing thermostats for plant B from a local supplier. A single lot was purchased from the local supplier and it was desired to test whether

* A test for the equality of standard deviations is given in Art. 4.10.

or not these new thermostats were as accurate as the old. It was decided to test the irons on the 550°F setting, and the actual temperatures were to be read to the nearest 0.1° with a thermocouple. With the old supplier, very few complaints were received, and the manufacturer feels that the switch should not be made if the average temperature changes by more than 10.5°. The order of magnitude of the standard deviation is roughly 10° for the old supplier, and there is no reason to suspect that it will be different for the new supplier. For $d = 10.5/(2 \times 10) = 0.525$, and from Fig. 13.29, $n' = 45$, corresponding to a probability of 0.9 of detecting a change of 10.5° or more. Hence $n = 23$. The data are:

New supplier x (degrees F)		Old supplier y (degrees F)	
530.3	559.1	559.7	564.6
559.3	555.0	534.7	554.5
549.4	538.6	554.8	553.0
544.0	551.1	545.0	538.4
551.7	565.4	544.6	548.3
566.3	554.9	538.0	552.9
549.9	550.0	550.7	535.1
556.9	554.9	563.1	555.0
536.7	544.7	551.1	544.8
558.8	536.1	553.8	558.4
538.8	569.1	538.8	548.7
	543.3		560.3

$$\sum x = 12{,}684.3 \qquad \sum y = 12{,}648.3$$
$$\bar{x} = 551.491304 \qquad \bar{y} = 549.926086$$
$$\sum x^2 = 6{,}997{,}436.07 \qquad \sum y^2 = 6{,}957{,}333.23$$
$$\sum (x_i - \bar{x})^2 = \sum x_i^2 - n\bar{x}^2 = 2{,}154.930$$
$$\sum (y_i - \bar{y})^2 = \sum y_i^2 - n\bar{y}^2 = 1{,}703.130$$
$$\frac{\sum (x_i - \bar{x})^2 + \sum (y_i - \bar{y})^2}{n_1 + n_2 - 2} = \frac{3858.06}{44} = 87.68318$$
$$|t| = \frac{551.491304 - 549.926086}{\sqrt{2/23}\sqrt{87.68318}} = 0.567 \leq t_{\alpha/2} = 2.02$$

Therefore we accept the hypothesis at the 5% level of significance that there is no difference in the mean temperatures of the two suppliers.

4.8.1 Procedure based on correlated samples. An important special case of the t test arises when the observations are "paired"; each pair being taken under the same experimental conditions, with the conditions varying from pair to pair. In this case, the test is made on the differences of the observations, and is carried out as a one sample problem, testing the hypothesis that the mean of the difference is zero according to the procedure of Art. 4.5, where the observations now consist of the differences.

Example. A research laboratory is embarking on an experiment to determine whether or not outside temperature has any effect on the accuracy of a Bourdon gage. The experiment consists of placing the gage in a steam line which is completely insulated from room temperature. The line passes through two adjacent rooms. One room always remains at 32°F, whereas the temperature in the other can be varied. Since there is a time lag in changing the

temperature of the controlled room, it is likely that the steam pressure will fluctuate during this time interval. Consequently, no effort is made to maintain the same pressure for a period of time. It can be assumed that the pressure is the same at the stations in each room and will be kept at approximately 60 psi. The experiment should be designed such that a difference as great as 0.75 psi should be picked up with high probability, say 0.9. The order of magnitude of the standard deviation is 0.4 psi. This is obtained as follows: The manufacturer usually specifies that these gages are good to $\pm 2\%$. If we interpret this to mean that most of the observations will lie between $\pm 2\%$ of the true value, and in particular, if "most" means 0.9987, we have true value $\pm 2\%$ = true value $\pm 3\sigma$. If the true value is near 60 psi, we have $3\sigma = 1.2$ or $\sigma = 0.4$. Hence the standard deviation of the differences is $(\sqrt{2})(0.4) = 0.57$. It must be emphasized that this is just an estimate of the order of magnitude of the standard deviation and should be used only for determining sample size. Referring to Fig. 13.29, $d = (0.75)/(\sqrt{2})(0.4) = 1.3$, so that eight observations are required. The data are:

Pressure read at room temp. = 32° x	Pressure read at other room temp. y	$x - y$	$(x - y)^2$
60.3	61.0	−0.7	0.49
59.9	60.0	−0.1	0.01
59.5	60.9	−1.4	1.96
58.5	58.2	0.3	0.09
59.6	59.9	−0.3	0.09
59.0	60.4	−1.4	1.96
60.1	59.6	0.5	0.25
59.4	59.9	−0.5	0.25

$$s^2 = \frac{5.10 - 8(0.450)^2}{7} = 0.497; \quad \sum (x - y) = -3.6; \quad \sum (x - y)^2 = 5.10$$

$$s = 0.705; \qquad |t| = \left|\frac{-0.45\sqrt{8}}{0.705}\right| = \frac{1.406}{0.705} = 1.99 \leq t_{\alpha/2} = 2.365$$

Therefore the data do not reveal any significant difference between gauge readings when the temperature changes.

4.9 TEST OF THE HYPOTHESIS THAT THE MEANS OF TWO NORMAL DISTRIBUTIONS ARE EQUAL WHEN THE STANDARD DEVIATIONS ARE UNKNOWN AND NOT NECESSARILY EQUAL

Notation for the hypothesis	*Test statistic*
$\mu_x = \mu_y$	$t' = \dfrac{\bar{x} - \bar{y}}{\sqrt{s_x^2/n_x + s_y^2/n_y}}$
Rule of rejection	*Formula for obtaining the degrees of freedom* ν
$t' \geq t_{\alpha;\nu}$ if we wish to reject when $\mu_x > \mu_y$.	$\nu = \dfrac{(s_x^2/n_x + s_y^2/n_y)^2}{(s_x^2/n_x)^2/(n_x + 1) + (s_y^2/n_y)^2/(n_y + 1)} - 2$
$t' \leq -t_{\alpha;\nu}$ if we wish to reject when $\mu_x < \mu_y$.	
$\lvert t'\rvert \geq t_{\alpha/2;\nu}$ if we wish to reject whenever μ_x is not equal to μ_y.	

Example. A manufacturer of automobile crankshafts was troubled with the problem of bend in the final shaft. Bend may be caused by the length and weight of the shaft, by improper setup of machine tools, by the heat treating process, or by some combination of these causes. It is suspected that nitriding the shaft, i.e., the process that hardens the surface of the shaft by a heat and nitrous oxide reaction with the steel, is the main cause for bend. Twenty-five shafts were measured before nitriding at the front main center journal by a dial indicator gauge accurate to the 0.0001 in. Similarly, another 25 shafts were measured at the same spot after the nitriding operation. It cannot be assumed that the variability in the bend is the same before and after nitriding. We test the hypothesis that the mean value of the bend is the same before and after nitriding, wishing to reject if the average bend after nitriding is larger. Denoting by x the values before nitriding and by y the values after nitriding, the following results were obtained:

$$\sum_{i=1}^{25} x = 203 \times 10^{-4} \qquad \sum_{i=1}^{25} y = 453 \times 10^{-4}$$

$$\bar{x} = 0.0008120 \qquad \bar{y} = 0.001812$$

$$\sum_{i=1}^{25} x^2 = 2{,}933 \times 10^{-8} \qquad \sum_{i=1}^{25} y^2 = 14{,}362 \times 10^{-8}$$

$$s_x^2 = \frac{2{,}933 \times 10^{-8} - 25(0.0008120)^2}{24} \qquad s_y^2 = \frac{14{,}362 \times 10^{-8} - 25(0.001812)^2}{24}$$

$$= 53.5 \times 10^{-8} \qquad = 256 \times 10^{-8}$$

$$\frac{s_x^2}{n_x} = 2.14 \times 10^{-8} \qquad \frac{s_y^2}{n_y} = 10.24 \times 10^{-8}$$

$$v = \frac{[(2.14)10^{-8} + (10.24)10^{-8}]^2}{(2.14)^2(10^{-16})/26 + (10.24)^2(10^{-16})/26} - 2 = 34$$

$$t' = \frac{0.0008120 - 0.001812}{\sqrt{(2.14)10^{-8} + (10.24)10^{-8}}} = -\frac{0.001}{(3.52)10^{-4}} = -2.84$$

$$t_{.05;34} = 1.69$$

Since $t' \leq t_{\alpha;v}$ we reject the hypothesis that at the 5% significance level the means are the same before and after nitriding, and we conclude that the average bend is larger after nitriding.

4.10 TEST OF THE HYPOTHESIS THAT THE VARIANCES OF TWO NORMAL DISTRIBUTIONS ARE EQUAL

Notation for the hypothesis	*Test statistic*
$\sigma_x^2 = \sigma_y^2$ or $\sigma_x = \sigma_y$	$F = \dfrac{[\sum (x_i - \bar{x})^2]/(n_x - 1)}{[\sum (y_i - \bar{y})^2]/(n_y - 1)} = \dfrac{s_x^2}{s_y^2}$
Rule of rejection	*Rule for choosing sample sizes*
$F \geq F_{\alpha;n_x-1,n_y-1}$ if we wish to reject when $\sigma_x > \sigma_y$. The notation x and y is arbitrary in a one-sided test; let x be the symbol for the variable with possible larger variance.	The OC curve depends on $\lambda = \sigma_x/\sigma_y$, and n_x and n_y. The OC curve for $n_x = n_y = n$ is given in Fig. 13.41 and 13.42. Pick a λ for which we want to reject and choose n such that the probability of accepting for that λ is sufficiently small.
In a two-sided test, let s_x^2 be the larger sample variance. Reject if $F \geq F_{\alpha/2;n_x-1,n_y-1}$.	The OC curve depends on $\lambda = \sigma_x/\sigma_y$ and is given in Fig. 13.39 and 13.40 for the case $n_x = n_y = n$. Pick the n for a specified λ such that the probability of accepting is sufficiently small.

Percentage points of the F distribution may be found in Table 13.27.

Example. The standard deviation of a particular dimension of a metal component is small enough so that it is satisfactory in subsequent assembly; a new supplier of metal plate is under consideration and will be preferred if the standard deviation of his product is not larger as the cost of his product is lower than that of the present supplier. From Fig. 13.41, it is decided to base this decision on a sample of 100 items from each supplier, since it is desired to insure that the probability of switching to the new product is less than 0.02 if $\lambda \geq 1.5$; data on dimensions are relatively easy to obtain, and small numbers of observations give relatively little protection against erroneous decisions. The following data are obtained:

$$\text{New supplier:} \quad s^2 = 0.00041$$

$$\text{Current supplier:} \quad s^2 = 0.00057$$

$$F = \frac{(0.00041)}{(0.00057)} < F_{.05;99,99}$$

Since the value of F does not exceed $F_{.05;99,99}$, the hypothesis of equality of variances is adopted.

TABLE 13.27 10 PERCENTAGE POINT OF THE F DISTRIBUTION★
Table of $F_{.10;\nu_1,\nu_2}$

Degrees of freedom for the denominator (ν_2)	Degrees of freedom for the numerator (ν_1)																	
	1	2	3	4	5	6	7	8	9	10	15	20	30	50	100	200	500	∞
1	39.9	49.5	53.6	55.8	57.2	58.2	58.9	59.4	59.9	60.2	61.2	61.7	62.3	62.7	63.0	63.2	63.3	63.3
2	8.53	9.00	9.16	9.24	9.29	9.33	9.35	9.37	9.38	9.39	9.42	9.44	9.46	9.47	9.48	9.49	9.40	9.49
3	5.54	5.46	5.39	5.34	5.31	5.28	5.27	5.25	5.24	5.23	5.20	5.18	5.17	5.15	5.14	5.14	5.14	5.13
4	4.54	4.32	4.19	4.11	4.05	4.01	3.98	3.95	3.94	3.92	3.87	3.84	3.82	3.80	3.78	3.77	3.76	3.76
5	4.06	3.78	3.62	3.52	3.45	3.40	3.37	3.34	3.32	3.30	3.24	3.21	3.17	3.15	3.13	3.12	3.11	3.10
6	3.78	3.46	3.29	3.18	3.11	3.05	3.01	2.98	2.96	2.94	2.87	2.84	2.80	2.77	2.75	2.73	2.73	2.72
7	3.59	3.26	3.07	2.96	2.88	2.83	2.78	2.75	2.72	2.70	2.63	2.59	2.56	2.52	2.50	2.48	2.48	2.47
8	3.46	3.11	2.92	2.81	2.73	2.67	2.62	2.59	2.56	2.54	2.46	2.42	2.38	2.35	2.32	2.31	2.30	2.29
9	3.36	3.01	2.81	2.69	2.61	2.55	2.51	2.47	2.44	2.42	2.34	2.30	2.25	2.22	2.19	2.17	2.17	2.16
10	3.28	2.92	2.73	2.61	2.52	2.46	2.41	2.38	2.35	2.32	2.24	2.20	2.16	2.12	2.09	2.07	2.06	2.06
11	3.23	2.86	2.66	2.54	2.45	2.39	2.34	2.30	2.27	2.25	2.17	2.12	2.08	2.04	2.00	1.99	1.98	1.97
12	3.18	2.81	2.61	2.48	2.39	2.33	2.28	2.24	2.21	2.19	2.10	2.06	2.01	1.97	1.94	1.92	1.91	1.90
13	3.14	2.76	2.56	2.43	2.35	2.28	2.23	2.20	2.16	2.14	2.05	2.01	1.96	1.92	1.88	1.86	1.85	1.85
14	3.10	2.73	2.52	2.39	2.31	2.24	2.19	2.15	2.12	2.10	2.01	1.96	1.91	1.87	1.83	1.82	1.80	1.80
15	3.07	2.70	2.49	2.36	2.27	2.21	2.16	2.12	2.09	2.06	1.97	1.92	1.87	1.83	1.79	1.77	1.76	1.76
16	3.05	2.67	2.46	2.33	2.24	2.18	2.13	2.09	2.06	2.03	1.94	1.89	1.84	1.79	1.76	1.74	1.73	1.72
17	3.03	2.64	2.44	2.31	2.22	2.15	2.10	2.06	2.03	2.00	1.91	1.86	1.81	1.76	1.73	1.71	1.69	1.69
18	3.01	2.62	2.42	2.29	2.20	2.13	2.08	2.04	2.00	1.98	1.89	1.84	1.78	1.74	1.70	1.68	1.67	1.66
19	2.99	2.61	2.40	2.27	2.18	2.11	2.06	2.02	1.98	1.96	1.86	1.81	1.76	1.71	1.67	1.65	1.64	1.63
20	2.97	2.59	2.38	2.25	2.16	2.09	2.04	2.00	1.96	1.94	1.84	1.79	1.74	1.69	1.65	1.63	1.62	1.61
22	2.95	2.56	2.35	2.22	2.13	2.06	2.01	1.97	1.93	1.90	1.81	1.76	1.70	1.65	1.61	1.59	1.58	1.57
24	2.93	2.54	2.33	2.19	2.10	2.04	1.98	1.94	1.91	1.88	1.78	1.73	1.67	1.62	1.58	1.56	1.54	1.53
26	2.91	2.52	2.31	2.17	2.08	2.01	1.96	1.92	1.88	1.86	1.76	1.71	1.65	1.59	1.55	1.53	1.51	1.50
28	2.89	2.50	2.29	2.16	2.06	2.00	1.94	1.90	1.87	1.84	1.74	1.69	1.63	1.57	1.53	1.50	1.49	1.48
30	2.88	2.49	2.28	2.14	2.05	1.98	1.93	1.88	1.85	1.82	1.72	1.67	1.61	1.55	1.51	1.48	1.47	1.46
40	2.84	2.44	2.23	2.09	2.00	1.93	1.87	1.83	1.79	1.76	1.66	1.61	1.54	1.48	1.43	1.41	1.39	1.38
50	2.81	2.41	2.20	2.06	1.97	1.90	1.84	1.80	1.76	1.73	1.63	1.57	1.50	1.44	1.39	1.36	1.34	1.33
60	2.79	2.39	2.18	2.04	1.95	1.87	1.82	1.77	1.74	1.71	1.60	1.54	1.48	1.41	1.36	1.33	1.31	1.29
80	2.77	2.37	2.15	2.02	1.92	1.85	1.79	1.75	1.71	1.68	1.57	1.51	1.44	1.38	1.32	1.28	1.26	1.24
100	2.76	2.36	2.14	2.00	1.91	1.83	1.78	1.73	1.70	1.66	1.56	1.49	1.42	1.35	1.29	1.26	1.23	1.21
200	2.73	2.33	2.11	1.97	1.88	1.80	1.75	1.70	1.66	1.63	1.52	1.46	1.38	1.31	1.24	1.20	1.17	1.14
500	2.72	2.31	2.10	1.96	1.86	1.79	1.73	1.68	1.64	1.61	1.50	1.44	1.36	1.28	1.21	1.16	1.12	1.09
∞	2.71	2.30	2.08	1.94	1.85	1.77	1.72	1.67	1.63	1.60	1.49	1.42	1.34	1.26	1.18	1.13	1.08	1.00

Example: $P\{F_{.10;9,18} < 2.00\} = 90\%$.

$F_{.90;\nu_1,\nu_2} = 1/F_{.10;\nu_2,\nu_1}$. Example: $F_{.90;8,20} = 1/F_{.10;20,8} = 1/2.42 = 0.413$.

Approximate formula for ν_1 and ν_2 larger than 30: $\log_{10} F_{.10;\nu_1,\nu_2} \simeq \dfrac{1.1131}{\sqrt{h - 0.77}} - 0.527\left(\dfrac{1}{\nu_1} - \dfrac{1}{\nu_2}\right)$,

where $\dfrac{1}{h} = \dfrac{1}{2}\left(\dfrac{1}{\nu_1} + \dfrac{1}{\nu_2}\right)$.

★ This table is abridged from *Statistical Tables and Formulas*, by A. Hald, published by John Wiley & Sons, Inc., a major part of which has been abridged from "Tables of Percentage Points of the Inverted Beta (F) Distribution," computed by M. Merrington and C. M. Thompson, *Biometrika* Vol. 33, 1943, 73-88, by permission of the proprietors, or reproduced from Table V of R. A. Fisher and F. Yates: *Statistical Tables*, Oliver and Boyd, Edinburgh, by permission of the authors and the publishers.

Degrees of freedom for the denominator (n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Degrees of freedom for the numerator (m)																	
1	161	200	216	225	230	234	237	239	241	242	243	244	245	245	246	246	247	247
2	18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
3	10.1	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.76	8.74	8.73	8.71	8.70	8.69	8.68	8.67
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.94	5.91	5.89	5.87	5.86	5.84	5.83	5.82
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.70	4.68	4.66	4.64	4.62	4.60	4.59	4.58
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.03	4.00	3.98	3.96	3.94	3.92	3.91	3.90
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.60	3.57	3.55	3.53	3.51	3.49	3.48	3.47
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.31	3.28	3.26	3.24	3.22	3.20	3.19	3.17
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.10	3.07	3.05	3.03	3.01	2.99	2.97	2.96
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.94	2.91	2.89	2.86	2.85	2.83	2.81	2.80
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.82	2.79	2.76	2.74	2.72	2.70	2.69	2.67
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.72	2.69	2.66	2.64	2.62	2.60	2.58	2.57
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.63	2.60	2.58	2.55	2.53	2.51	2.50	2.48
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.57	2.53	2.51	2.48	2.46	2.44	2.43	2.41
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.51	2.48	2.45	2.42	2.40	2.38	2.37	2.35
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.46	2.42	2.40	2.37	2.35	2.33	2.32	2.30
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.41	2.38	2.35	2.33	2.31	2.29	2.27	2.26
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.37	2.34	2.31	2.29	2.27	2.25	2.23	2.22
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.34	2.31	2.28	2.26	2.23	2.21	2.20	2.18
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.31	2.28	2.25	2.22	2.20	2.18	2.17	2.15
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.28	2.25	2.22	2.20	2.18	2.16	2.14	2.12
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.26	2.23	2.20	2.17	2.15	2.13	2.11	2.10
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.23	2.20	2.18	2.15	2.13	2.11	2.09	2.07
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.21	2.18	2.15	2.13	2.11	2.09	2.07	2.05
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.20	2.16	2.14	2.11	2.09	2.07	2.05	2.04
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.18	2.15	2.12	2.09	2.07	2.05	2.03	2.02
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.17	2.13	2.10	2.08	2.06	2.04	2.02	2.00
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.15	2.12	2.09	2.06	2.04	2.02	2.00	1.99
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.14	2.10	2.08	2.05	2.03	2.01	1.99	1.97
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.13	2.09	2.06	2.04	2.01	1.99	1.98	1.96
32	4.15	3.29	2.90	2.67	2.51	2.40	2.31	2.24	2.19	2.14	2.10	2.07	2.04	2.01	1.99	1.97	1.95	1.94
34	4.13	3.28	2.88	2.65	2.49	2.38	2.29	2.23	2.17	2.12	2.08	2.05	2.02	1.99	1.97	1.95	1.93	1.92
36	4.11	3.26	2.87	2.63	2.48	2.36	2.28	2.21	2.15	2.11	2.07	2.03	2.00	1.98	1.95	1.93	1.92	1.90
38	4.10	3.24	2.85	2.62	2.46	2.35	2.26	2.19	2.14	2.09	2.05	2.02	1.99	1.96	1.94	1.92	1.90	1.88
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.04	2.00	1.97	1.95	1.92	1.90	1.89	1.87
42	4.07	3.22	2.83	2.59	2.44	2.32	2.24	2.17	2.11	2.06	2.03	1.99	1.96	1.93	1.91	1.89	1.87	1.86
44	4.06	3.21	2.82	2.58	2.43	2.31	2.23	2.16	2.10	2.05	2.01	1.98	1.95	1.92	1.90	1.88	1.86	1.84
46	4.05	3.20	2.81	2.57	2.42	2.30	2.22	2.15	2.09	2.04	2.00	1.97	1.94	1.91	1.89	1.87	1.85	1.83
48	4.04	3.19	2.80	2.57	2.41	2.29	2.21	2.14	2.08	2.03	1.99	1.96	1.93	1.90	1.88	1.86	1.84	1.82
50	4.03	3.18	2.79	2.56	2.40	2.29	2.20	2.13	2.07	2.03	1.99	1.95	1.92	1.89	1.87	1.85	1.83	1.81
55	4.02	3.16	2.77	2.54	2.38	2.27	2.18	2.11	2.06	2.01	1.97	1.93	1.90	1.88	1.85	1.83	1.81	1.79
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.95	1.92	1.89	1.86	1.84	1.82	1.80	1.78
65	3.99	3.14	2.75	2.51	2.36	2.24	2.15	2.08	2.03	1.98	1.94	1.90	1.87	1.85	1.82	1.80	1.78	1.76
70	3.98	3.13	2.74	2.50	2.35	2.23	2.14	2.07	2.02	1.97	1.93	1.89	1.86	1.84	1.81	1.79	1.77	1.75
80	3.96	3.11	2.72	2.49	2.33	2.21	2.13	2.06	2.00	1.95	1.91	1.88	1.84	1.82	1.79	1.77	1.75	1.73
90	3.95	3.10	2.71	2.47	2.32	2.20	2.11	2.04	1.99	1.94	1.90	1.86	1.83	1.80	1.78	1.76	1.74	1.72
100	3.94	3.09	2.70	2.46	2.31	2.19	2.10	2.03	1.97	1.93	1.89	1.85	1.82	1.79	1.77	1.75	1.73	1.71
125	3.92	3.07	2.68	2.44	2.29	2.17	2.08	2.01	1.96	1.91	1.87	1.83	1.80	1.77	1.75	1.72	1.70	1.69
150	3.90	3.06	2.66	2.43	2.27	2.16	2.07	2.00	1.94	1.89	1.85	1.82	1.79	1.76	1.73	1.71	1.69	1.67
200	3.89	3.04	2.65	2.42	2.26	2.14	2.06	1.98	1.93	1.88	1.84	1.80	1.77	1.74	1.72	1.69	1.67	1.66
300	3.87	3.03	2.63	2.40	2.24	2.13	2.04	1.97	1.91	1.86	1.82	1.78	1.75	1.72	1.70	1.68	1.66	1.64
500	3.86	3.01	2.62	2.39	2.23	2.12	2.03	1.96	1.90	1.85	1.81	1.77	1.74	1.71	1.69	1.66	1.64	1.62
1000	3.85	3.00	2.61	2.38	2.22	2.11	2.02	1.95	1.89	1.84	1.80	1.76	1.73	1.70	1.68	1.65	1.63	1.61
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.79	1.75	1.72	1.69	1.67	1.64	1.62	1.60

Example: $P\{F_{.95;8,20} < 2.45\} = 95\%$.

$F_{.05;\nu_1,\nu_2} = 1/F_{.95;\nu_2,\nu_1}$. Example: $F_{.05;8,20} = 1/F_{.95;20,8} = 1/3.15 = 0.317$.

$F_{.05;\nu_1,\nu_2}$

Degrees of freedom for the numerator (ν_1)																	Degrees of freedom for the denominator (ν_2)
19	20	22	24	26	28	30	35	40	45	50	60	80	100	200	500	∞	
248	248	249	249	249	250	250	251	251	251	252	252	252	253	254	254	254	1
19.4	19.4	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	2
8.67	8.66	8.65	8.64	8.63	8.62	8.62	8.60	8.59	8.59	8.58	8.57	8.56	8.55	8.54	8.53	8.53	3
5.81	5.80	5.79	5.77	5.76	5.75	5.75	5.73	5.72	5.71	5.70	5.69	5.67	5.66	5.65	5.64	5.63	4
4.57	4.56	4.54	4.53	4.52	4.50	4.50	4.48	4.46	4.45	4.44	4.43	4.41	4.41	4.39	4.37	4.37	5
3.88	3.87	3.86	3.84	3.83	3.82	3.81	3.79	3.77	3.76	3.75	3.74	3.72	3.71	3.69	3.68	3.67	6
3.46	3.44	3.43	3.41	3.40	3.39	3.38	3.36	3.34	3.33	3.32	3.30	3.29	3.27	3.25	3.24	3.23	7
3.16	3.15	3.13	3.12	3.10	3.09	3.08	3.06	3.04	3.03	3.02	3.01	2.99	2.97	2.95	2.94	2.93	8
2.95	2.94	2.92	2.90	2.89	2.87	2.86	2.84	2.83	2.81	2.80	2.79	2.77	2.76	2.73	2.72	2.71	9
2.78	2.77	2.75	2.74	2.72	2.71	2.70	2.68	2.66	2.65	2.64	2.62	2.60	2.59	2.56	2.55	2.54	10
2.66	2.65	2.63	2.61	2.59	2.58	2.57	2.55	2.53	2.52	2.51	2.49	2.47	2.46	2.43	2.42	2.40	11
2.56	2.54	2.52	2.51	2.49	2.48	2.47	2.44	2.43	2.41	2.40	2.38	2.36	2.35	2.32	2.31	2.30	12
2.47	2.46	2.44	2.42	2.41	2.39	2.38	2.36	2.34	2.33	2.31	2.30	2.27	2.26	2.23	2.22	2.21	13
2.40	2.39	2.37	2.35	2.33	2.32	2.31	2.28	2.27	2.25	2.24	2.22	2.20	2.19	2.16	2.14	2.13	14
2.34	2.33	2.31	2.29	2.27	2.26	2.25	2.22	2.20	2.19	2.18	2.16	2.14	2.12	2.10	2.08	2.07	15
2.29	2.28	2.25	2.24	2.22	2.21	2.19	2.17	2.15	2.14	2.12	2.11	2.08	2.07	2.04	2.02	2.01	16
2.24	2.23	2.21	2.19	2.17	2.16	2.15	2.12	2.10	2.09	2.08	2.06	2.03	2.02	1.99	1.97	1.96	17
2.20	2.19	2.17	2.15	2.13	2.12	2.11	2.08	2.06	2.05	2.04	2.02	1.99	1.98	1.95	1.93	1.92	18
2.17	2.16	2.13	2.11	2.10	2.08	2.07	2.05	2.03	2.01	2.00	1.98	1.96	1.94	1.91	1.89	1.88	19
2.14	2.12	2.10	2.08	2.07	2.05	2.04	2.01	1.99	1.98	1.97	1.95	1.92	1.91	1.88	1.86	1.84	20
2.11	2.10	2.07	2.05	2.04	2.02	2.01	1.98	1.96	1.95	1.94	1.92	1.89	1.88	1.84	1.82	1.81	21
2.08	2.07	2.05	2.03	2.01	2.00	1.98	1.96	1.94	1.92	1.91	1.89	1.86	1.85	1.82	1.80	1.78	22
2.06	2.05	2.02	2.00	1.99	1.97	1.96	1.93	1.91	1.90	1.88	1.86	1.84	1.82	1.79	1.77	1.76	23
2.04	2.03	2.00	1.98	1.97	1.95	1.94	1.91	1.89	1.88	1.86	1.84	1.82	1.80	1.77	1.75	1.73	24
2.02	2.01	1.98	1.96	1.95	1.93	1.92	1.89	1.87	1.86	1.84	1.82	1.80	1.78	1.75	1.73	1.71	25
2.00	1.99	1.97	1.95	1.93	1.91	1.90	1.87	1.85	1.84	1.82	1.80	1.78	1.76	1.73	1.71	1.69	26
1.99	1.97	1.95	1.93	1.91	1.90	1.88	1.86	1.84	1.82	1.81	1.79	1.76	1.74	1.71	1.69	1.67	27
1.97	1.96	1.93	1.91	1.90	1.88	1.87	1.84	1.82	1.80	1.79	1.77	1.74	1.73	1.69	1.67	1.65	28
1.96	1.94	1.92	1.90	1.88	1.87	1.85	1.83	1.81	1.79	1.77	1.75	1.73	1.71	1.67	1.65	1.64	29
1.95	1.93	1.91	1.89	1.87	1.85	1.84	1.81	1.79	1.77	1.76	1.74	1.71	1.70	1.66	1.64	1.62	30
1.92	1.91	1.88	1.86	1.85	1.83	1.82	1.79	1.77	1.75	1.74	1.71	1.69	1.67	1.63	1.61	1.59	32
1.90	1.89	1.86	1.84	1.82	1.80	1.80	1.77	1.75	1.73	1.71	1.69	1.66	1.65	1.61	1.59	1.57	34
1.88	1.87	1.85	1.82	1.81	1.79	1.78	1.75	1.73	1.71	1.69	1.67	1.64	1.62	1.59	1.56	1.55	36
1.87	1.85	1.83	1.81	1.79	1.77	1.76	1.73	1.71	1.69	1.68	1.65	1.62	1.61	1.57	1.54	1.53	38
1.85	1.84	1.81	1.79	1.77	1.76	1.74	1.72	1.69	1.67	1.66	1.64	1.61	1.59	1.55	1.53	1.51	40
1.84	1.83	1.80	1.78	1.76	1.74	1.73	1.70	1.68	1.66	1.65	1.62	1.59	1.57	1.53	1.51	1.49	42
1.83	1.81	1.79	1.77	1.75	1.73	1.72	1.69	1.67	1.65	1.63	1.61	1.58	1.56	1.52	1.49	1.48	44
1.82	1.80	1.78	1.76	1.74	1.72	1.71	1.68	1.65	1.64	1.62	1.60	1.57	1.55	1.51	1.48	1.46	46
1.81	1.79	1.77	1.75	1.73	1.71	1.70	1.67	1.64	1.62	1.61	1.59	1.56	1.54	1.49	1.47	1.45	48
1.80	1.78	1.76	1.74	1.72	1.70	1.69	1.66	1.63	1.61	1.60	1.58	1.54	1.52	1.48	1.46	1.44	50
1.78	1.76	1.74	1.72	1.70	1.68	1.67	1.64	1.61	1.59	1.58	1.55	1.52	1.50	1.46	1.43	1.41	55
1.76	1.75	1.72	1.70	1.68	1.66	1.65	1.62	1.59	1.57	1.56	1.53	1.50	1.48	1.44	1.41	1.39	60
1.75	1.73	1.71	1.69	1.67	1.65	1.63	1.60	1.58	1.56	1.54	1.52	1.49	1.46	1.42	1.39	1.37	65
1.74	1.72	1.70	1.67	1.65	1.64	1.62	1.59	1.57	1.55	1.53	1.50	1.47	1.45	1.40	1.37	1.35	70
1.72	1.70	1.68	1.65	1.63	1.62	1.60	1.57	1.54	1.52	1.51	1.48	1.45	1.43	1.38	1.35	1.32	80
1.70	1.69	1.66	1.64	1.62	1.60	1.59	1.55	1.53	1.51	1.49	1.46	1.43	1.41	1.36	1.32	1.30	90
1.69	1.68	1.65	1.63	1.61	1.59	1.57	1.54	1.52	1.49	1.48	1.45	1.41	1.39	1.34	1.31	1.28	100
1.67	1.65	1.63	1.60	1.58	1.57	1.55	1.52	1.49	1.47	1.43	1.42	1.39	1.36	1.31	1.27	1.25	125
1.66	1.64	1.61	1.59	1.57	1.55	1.53	1.50	1.48	1.45	1.44	1.41	1.37	1.34	1.29	1.25	1.22	150
1.64	1.62	1.60	1.57	1.55	1.53	1.52	1.48	1.46	1.43	1.41	1.39	1.35	1.32	1.26	1.22	1.19	200
1.62	1.61	1.58	1.55	1.53	1.51	1.50	1.46	1.43	1.41	1.39	1.36	1.32	1.30	1.23	1.19	1.15	300
1.61	1.59	1.56	1.54	1.52	1.50	1.48	1.45	1.42	1.40	1.38	1.34	1.30	1.28	1.21	1.16	1.11	500
1.60	1.58	1.55	1.53	1.51	1.49	1.47	1.44	1.41	1.38	1.36	1.33	1.29	1.26	1.19	1.13	1.08	1000
1.59	1.57	1.54	1.52	1.50	1.48	1.46	1.42	1.39	1.37	1.35	1.32	1.27	1.24	1.17	1.11	1.00	∞

Approximate formula for ν_1 and ν_2 larger than 30: $\log_{10} F_{.05;\nu_1,\nu_2} \simeq \dfrac{1.4287}{\sqrt{h} - 0.95} - 0.681\left(\dfrac{1}{\nu_1} - \dfrac{1}{\nu_2}\right)$, where $\dfrac{1}{h} = \dfrac{1}{2}\left(\dfrac{1}{\nu_1} + \dfrac{1}{\nu_2}\right)$.

Degrees of freedom for the numerator (ν_1); Degrees of freedom for the denominator (ν_2)

ν_2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	648	800	864	900	922	937	948	957	963	969	973	977	980	983	985	987	989	990
2	38.5	39.0	39.2	39.2	39.3	39.3	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4	39.4
3	17.4	16.0	15.4	15.1	14.9	14.7	14.6	14.5	14.5	14.4	14.4	14.3	14.3	14.3	14.3	14.2	14.2	14.2
4	12.2	10.6	9.98	9.60	9.36	9.20	9.07	8.98	8.90	8.84	8.79	8.75	8.72	8.69	8.66	8.64	8.62	8.60
5	10.0	8.43	7.76	7.39	7.15	6.98	6.85	6.76	6.68	6.62	6.57	6.52	6.49	6.46	6.43	6.41	6.39	6.37
6	8.81	7.26	6.60	6.23	5.99	5.82	5.70	5.60	5.52	5.46	5.41	5.37	5.33	5.30	5.27	5.25	5.23	5.21
7	8.07	6.54	5.89	5.52	5.29	5.12	4.99	4.90	4.82	4.76	4.71	4.67	4.63	4.60	4.57	4.54	4.52	4.50
8	7.57	6.06	5.42	5.05	4.82	4.65	4.53	4.43	4.36	4.30	4.24	4.20	4.16	4.13	4.10	4.08	4.05	4.03
9	7.21	5.71	5.08	4.72	4.48	4.32	4.20	4.10	4.03	3.96	3.91	3.87	3.83	3.80	3.77	3.74	3.72	3.70
10	6.94	5.46	4.83	4.47	4.24	4.07	3.95	3.85	3.78	3.72	3.66	3.62	3.58	3.55	3.52	3.50	3.47	3.45
11	6.72	5.26	4.63	4.28	4.04	3.88	3.76	3.66	3.59	3.53	3.47	3.43	3.39	3.36	3.33	3.30	3.28	3.26
12	6.55	5.10	4.47	4.12	3.89	3.73	3.61	3.51	3.44	3.37	3.32	3.28	3.24	3.21	3.18	3.15	3.13	3.11
13	6.41	4.97	4.35	4.00	3.77	3.60	3.48	3.39	3.31	3.25	3.20	3.15	3.12	3.08	3.05	3.03	3.00	2.98
14	6.30	4.86	4.24	3.89	3.66	3.50	3.38	3.29	3.21	3.15	3.09	3.05	3.01	2.98	2.95	2.92	2.90	2.88
15	6.20	4.76	4.15	3.80	3.58	3.41	3.29	3.20	3.12	3.06	3.01	2.96	2.92	2.89	2.86	2.84	2.81	2.79
16	6.12	4.69	4.08	3.73	3.50	3.34	3.22	3.12	3.05	2.99	2.93	2.89	2.85	2.82	2.79	2.76	2.74	2.72
17	6.04	4.62	4.01	3.66	3.44	3.28	3.16	3.06	2.98	2.92	2.87	2.82	2.79	2.75	2.72	2.70	2.67	2.65
18	5.98	4.56	3.95	3.61	3.38	3.22	3.10	3.01	2.93	2.87	2.81	2.77	2.73	2.70	2.67	2.64	2.62	2.60
19	5.92	4.51	3.90	3.56	3.33	3.17	3.05	2.96	2.88	2.82	2.76	2.72	2.68	2.65	2.62	2.59	2.57	2.55
20	5.87	4.46	3.86	3.51	3.29	3.13	3.01	2.91	2.84	2.77	2.72	2.68	2.64	2.60	2.57	2.55	2.52	2.50
21	5.83	4.42	3.82	3.48	3.25	3.09	2.97	2.87	2.80	2.73	2.68	2.64	2.60	2.56	2.53	2.51	2.48	2.46
22	5.79	4.38	3.78	3.44	3.22	3.05	2.93	2.84	2.76	2.70	2.65	2.60	2.56	2.53	2.50	2.47	2.45	2.43
23	5.75	4.35	3.75	3.41	3.18	3.02	2.90	2.81	2.73	2.67	2.62	2.57	2.53	2.50	2.47	2.44	2.42	2.39
24	5.72	4.32	3.72	3.38	3.15	2.99	2.87	2.78	2.70	2.64	2.59	2.54	2.50	2.47	2.44	2.41	2.39	2.36
25	5.69	4.29	3.69	3.35	3.13	2.97	2.85	2.75	2.68	2.61	2.56	2.51	2.48	2.44	2.41	2.38	2.36	2.34
26	5.66	4.27	3.67	3.33	3.10	2.94	2.82	2.73	2.65	2.59	2.54	2.49	2.45	2.42	2.39	2.36	2.34	2.31
27	5.63	4.24	3.65	3.31	3.08	2.92	2.80	2.71	2.63	2.57	2.51	2.47	2.43	2.39	2.36	2.34	2.31	2.29
28	5.61	4.22	3.63	3.29	3.06	2.90	2.78	2.69	2.61	2.55	2.49	2.45	2.41	2.37	2.34	2.32	2.29	2.27
29	5.59	4.20	3.61	3.27	3.04	2.88	2.76	2.67	2.59	2.53	2.48	2.43	2.39	2.36	2.32	2.30	2.27	2.25
30	5.57	4.18	3.59	3.25	3.03	2.87	2.75	2.65	2.57	2.51	2.46	2.41	2.37	2.34	2.31	2.28	2.26	2.23
32	5.53	4.15	3.56	3.22	3.00	2.84	2.72	2.62	2.54	2.48	2.43	2.38	2.34	2.31	2.28	2.25	2.22	2.20
34	5.50	4.12	3.53	3.19	2.97	2.81	2.69	2.59	2.52	2.45	2.40	2.35	2.31	2.28	2.25	2.22	2.19	2.17
36	5.47	4.09	3.51	3.17	2.94	2.79	2.66	2.57	2.49	2.43	2.37	2.33	2.29	2.25	2.22	2.20	2.17	2.15
38	5.45	4.07	3.48	3.15	2.92	2.76	2.64	2.55	2.47	2.41	2.35	2.31	2.27	2.23	2.20	2.17	2.15	2.13
40	5.42	4.05	3.46	3.13	2.90	2.74	2.62	2.53	2.45	2.39	2.33	2.29	2.25	2.21	2.18	2.15	2.13	2.11
42	5.40	4.03	3.45	3.11	2.89	2.73	2.61	2.51	2.44	2.37	2.32	2.27	2.23	2.20	2.16	2.14	2.11	2.09
44	5.39	4.02	3.43	3.09	2.87	2.71	2.59	2.50	2.42	2.36	2.30	2.26	2.21	2.18	2.15	2.12	2.10	2.07
46	5.37	4.00	3.42	3.08	2.86	2.70	2.58	2.48	2.41	2.34	2.29	2.24	2.20	2.17	2.13	2.11	2.08	2.06
48	5.35	3.99	3.40	3.07	2.84	2.69	2.57	2.47	2.39	2.33	2.27	2.23	2.19	2.15	2.12	2.09	2.07	2.05
50	5.34	3.98	3.39	3.06	2.83	2.67	2.55	2.46	2.38	2.32	2.26	2.22	2.18	2.14	2.11	2.08	2.06	2.03
55	5.31	3.95	3.36	3.03	2.81	2.65	2.53	2.43	2.36	2.29	2.24	2.19	2.15	2.11	2.08	2.05	2.03	2.01
60	5.29	3.93	3.34	3.01	2.79	2.63	2.51	2.41	2.33	2.27	2.22	2.17	2.13	2.09	2.06	2.03	2.01	1.98
65	5.27	3.91	3.32	2.99	2.77	2.61	2.49	2.39	2.32	2.25	2.20	2.15	2.11	2.07	2.04	2.01	1.99	1.97
70	5.25	3.89	3.31	2.98	2.75	2.60	2.48	2.38	2.30	2.24	2.18	2.14	2.10	2.06	2.03	2.00	1.97	1.95
80	5.22	3.86	3.28	2.95	2.73	2.57	2.45	2.36	2.28	2.21	2.16	2.11	2.07	2.03	2.00	1.97	1.95	1.93
90	5.20	3.84	3.27	2.93	2.71	2.55	2.43	2.34	2.26	2.19	2.14	2.09	2.05	2.02	1.98	1.95	1.93	1.91
100	5.18	3.83	3.25	2.92	2.70	2.54	2.42	2.32	2.24	2.18	2.12	2.08	2.04	2.00	1.97	1.94	1.91	1.89
125	5.15	3.80	3.22	2.89	2.67	2.51	2.39	2.30	2.22	2.15	2.10	2.05	2.01	1.97	1.94	1.91	1.89	1.86
150	5.13	3.78	3.20	2.87	2.65	2.49	2.37	2.28	2.20	2.13	2.08	2.03	1.99	1.95	1.92	1.89	1.87	1.84
200	5.10	3.76	3.18	2.85	2.63	2.47	2.35	2.26	2.18	2.11	2.06	2.01	1.97	1.93	1.90	1.87	1.84	1.82
300	5.08	3.74	3.16	2.83	2.61	2.45	2.33	2.23	2.16	2.09	2.04	1.99	1.95	1.91	1.88	1.85	1.82	1.80
500	5.05	3.72	3.14	2.81	2.59	2.43	2.31	2.22	2.14	2.07	2.02	1.97	1.93	1.89	1.86	1.83	1.80	1.78
1000	5.04	3.70	3.13	2.80	2.58	2.42	2.30	2.20	2.13	2.06	2.01	1.96	1.92	1.88	1.85	1.82	1.79	1.77
∞	5.02	3.69	3.12	2.79	2.57	2.41	2.29	2.19	2.11	2.05	1.99	1.94	1.90	1.87	1.83	1.80	1.78	1.75

Example: $P\{F_{.975;8,20} < 2.91\} = 97.5\%$.

$F_{.025;\nu_1,\nu_2} = 1/F_{.975;\nu_2,\nu_1}$. Example: $F_{.025;8,20} = 1/F_{.975;20,8} = 1/4.00 = 0.250$.

$F_{.025;\nu_1,\nu_2}$

Degrees of freedom for the numerator (ν_1)																	
19	20	22	24	26	28	30	35	40	45	50	60	80	100	200	500	∞	Degrees of freedom for the denominator (ν_2)
992	993	995	997	999	1000	1001	1004	1006	1007	1008	1010	1012	1013	1016	1017	1018	1
39.4	39.4	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	2
14.2	14.2	14.1	14.1	14.1	14.1	14.1	14.1	14.0	14.0	14.0	14.0	14.0	14.0	13.9	13.9	13.9	3
8.58	8.56	8.53	8.51	8.49	8.48	8.46	8.44	8.41	8.39	8.38	8.36	8.33	8.32	8.29	8.27	8.26	4
6.35	6.33	6.30	6.28	6.26	6.24	6.23	6.20	6.18	6.16	6.14	6.12	6.10	6.08	6.05	6.03	6.02	5
5.19	5.17	5.14	5.12	5.10	5.08	5.07	5.04	5.01	4.99	4.98	4.96	4.93	4.92	4.88	4.86	4.85	6
4.48	4.47	4.44	4.42	4.39	4.38	4.36	4.33	4.31	4.29	4.28	4.25	4.23	4.21	4.18	4.16	4.14	7
4.02	4.00	3.97	3.95	3.93	3.91	3.89	3.86	3.84	3.82	3.81	3.78	3.76	3.74	3.70	3.68	3.67	8
3.68	3.67	3.64	3.61	3.59	3.58	3.56	3.53	3.51	3.49	3.47	3.45	3.42	3.40	3.37	3.35	3.33	9
3.44	3.42	3.39	3.37	3.34	3 33	3.31	3.28	3.26	3.24	3.22	3.20	3.17	3.15	3.12	3.09	3.08	10
3.24	3.23	3.20	3.17	3.15	3.13	3.12	3.09	3.06	3.04	3.03	3.00	2.97	2.96	2.92	2.90	2.88	11
3.09	3.07	3.04	3.02	3.00	2.98	2.96	2.93	2.91	2.89	2.87	2.85	2.82	2.80	2.76	2.74	2.72	12
2.96	2.95	2.92	2.89	2.87	2.85	2.84	2.80	2.78	2.76	2.74	2.72	2.69	2.67	2.63	2.61	2.60	13
2.86	2.84	2.81	2.79	2.77	2.75	2.73	2.70	2.67	2.65	2.64	2.61	2.58	2.56	2.53	2.50	2.49	14
2.77	2.76	2.73	2.70	2.68	2.66	2.64	2.61	2.58	2.56	2.55	2.52	2.49	2.47	2.44	2.41	2.40	15
2.70	2.68	2.65	2.63	2.60	2.58	2.57	2.53	2.51	2.49	2.47	2.45	2.42	2.40	2.36	2.33	2.32	16
2.63	2.62	2.59	2.56	2.54	2.52	2.50	2.47	2.44	2.42	2.41	2.38	2.35	2.33	2.29	2.26	2.25	17
2.58	2.56	2.53	2.50	2.48	2.46	2.44	2.41	2.38	2.36	2.35	2.32	2.29	2.27	2.23	2.20	2.19	18
2.53	2.51	2.48	2.45	2.43	2.41	2.39	2.36	2.33	2.31	2.30	2.27	2.24	2.22	2.18	2.15	2.13	19
2.48	2.46	2.43	2.41	2.39	2.37	2.35	2.31	2.29	2.27	2.25	2.22	2.19	2.17	2.13	2.10	2.09	20
2.44	2.42	2 39	2.37	2.34	2.33	2.31	2.27	2.25	2.23	2.21	2.18	2.15	2.13	2.09	2.06	2.04	21
2.41	2.39	2.36	2.33	2.31	2.29	2.27	2.24	2.21	2.19	2.17	2.14	2.11	2.09	2.05	2.02	2.00	22
2.37	2.36	2.33	2.30	2.28	2.26	2.24	2.20	2.18	2.15	2.14	2.11	2.08	2.06	2.01	1.99	1.97	23
2.35	2.33	2 30	2.27	2.25	2.23	2.21	2 17	2.15	2.12	2.11	2.08	2.05	2.02	1.98	1 95	1.94	24
2.32	2.30	2.27	2.24	2.22	2.20	2.18	2.15	2.12	2.10	2.08	2.05	2.02	2.00	1.95	1.92	1.91	25
2.29	2.28	2.24	2.22	2.19	2.17	2.16	2.12	2.09	2.07	2 05	2.03	1.99	1.97	1.92	1.90	1 88	26
2.27	2.25	2.22	2.19	2.17	2.15	2.13	2.10	2.07	2 05	2.03	2.00	1.97	1.94	1.90	1.87	1 85	27
2.25	2.23	2.20	2.17	2.15	2.13	2.11	2.08	2.05	2.03	2 01	1.98	1.94	1.92	1.88	1.85	1.83	28
2.23	2.21	2.18	2.15	2.13	2.11	2.09	2.06	2.03	2.01	1.99	1.96	1.92	1.90	1.86	1.83	1.81	29
2.21	2.20	2.16	2.14	2.11	2.09	2.07	2.04	2.01	1.99	1.97	1.94	1.90	1.88	1.84	1.81	1.79	30
2.18	2.16	2.13	2.10	2.08	2.06	2.04	2.00	1.98	1.95	1.93	1.91	1.87	1.85	1.80	1.77	1.75	32
2.15	2.13	2.10	2 07	2.05	2.03	2.01	1.97	1.95	1.92	1.90	1.88	1.84	1.82	1.77	1.74	1.72	34
2.13	2.11	2.08	2.05	2 03	2.00	1.99	1.95	1.92	1.90	1.88	1.85	1.81	1.79	1.74	1.71	1.69	36
2.11	2.09	2.05	2.03	2.00	1.98	1.96	1.93	1.90	1.87	1.85	1.82	1.79	1.76	1.71	1.68	1.66	38
2.09	2.07	2.03	2.01	1.98	1.96	1.94	1.90	1.88	1.85	1.83	1.80	1.76	1.74	1.69	1.66	1 64	40
2.07	2.05	2.02	1.99	1.96	1.94	1.92	1.89	1.86	1.83	1.81	1.78	1.74	1.72	1 67	1.64	1 62	42
2.05	2.03	2.00	1.97	1.95	1.93	1.91	1.87	1.84	1.82	1.80	1 77	1.73	1.70	1.65	1.62	1 60	44
2.04	2.02	1.99	1.96	1.93	1.91	1.89	1.85	1.82	1.80	1.78	1.75	1.71	1.69	1.63	1.60	1.58	46
2.02	2.01	1.97	1.94	1.92	1.90	1.88	1.84	1.81	1.79	1.77	1.73	1.69	1.67	1.62	1.58	1.56	48
2.01	1.99	1.96	1 93	1.91	1.88	1.87	1.83	1.80	1.77	1.75	1.72	1.68	1.66	1.60	1 57	1.55	50
1.99	1.97	1.93	1.90	1.88	1.86	1.84	1.80	1.77	1.74	1.72	1.69	1.65	1.62	1.57	1.54	1.51	55
1.96	1.94	1.91	1.88	1.86	1.83	1.82	1.78	1.74	1.72	1.70	1.67	1.62	1.60	1.54	1.51	1.48	60
1.95	1.93	1.89	1.86	1.84	1.82	1.80	1.76	1.72	1.70	1.68	1.65	1.60	1.58	1.52	1.48	1.46	35
1.93	1.91	1.88	1.85	1.82	1.80	1.78	1.74	1.71	1.68	1.66	1.63	1.58	1.56	1.50	1.46	1.44	70
1.90	1.88	1.85	1.82	1.79	1.77	1.75	1.71	1.68	1.65	1.63	1.60	1.55	1.53	1.47	1.43	1.40	80
1.88	1.86	1.83	1.80	1.77	1.75	1.73	1.69	1.66	1.63	1.61	1.58	1.53	1.50	1.44	1 40	1.37	90
1.87	1.85	1.81	1.78	1.76	1.74	1.71	1.67	1.64	1.61	1.59	1.56	1.51	1.48	1.42	1.38	1 35	100
1.84	1.82	1.79	1.75	1.73	1.71	1.68	1.64	1.61	1.58	1.56	1.52	1.48	1.45	1.38	1.34	1.30	125
1.82	1.80	1.77	1.74	1.71	1.69	1.67	1.62	1.59	1.56	1.54	1.50	1.45	1.42	1.35	1.31	1.27	150
1.80	1.78	1.74	1.71	1.68	1.66	1.64	1.60	1.56	1.53	1.51	1.47	1.42	1.39	1.32	1.27	1.23	200
1.77	1.75	1.72	1.69	1.66	1.64	1.62	1.57	1.54	1.51	1.48	1.45	1.39	1.36	1.28	1.23	1.18	300
1.76	1.74	1.70	1.67	1.64	1.62	1.60	1.55	1.51	1.49	1.46	1.42	1.37	1.34	1.25	1.19	1.14	500
1.74	1.72	1.69	1.65	1 63	1.60	1.58	1.54	1.50	1.47	1.44	1.41	1.35	1.32	1.23	1.16	1.09	1000
1.73	1.71	1.67	1.64	1.61	1.59	1.57	1.52	1.48	1.45	1.43	1.39	1.33	1.30	1.21	1.13	1.00	∞

Approximate formula for ν_1 and ν_2 larger than 30: $\log_{10} F_{.025;\nu_1,\nu_2} \cong \frac{1.7023}{\sqrt{h - 1.14}} - 0.846\left(\frac{1}{\nu_1} - \frac{1}{\nu_2}\right)$, where $\frac{1}{h} = \frac{1}{2}\left(\frac{1}{\nu_1} + \frac{1}{\nu_2}\right)$.

Degrees of freedom for the denominator (ν_2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Multiply the numbers of the first row (ν_2 = 1) by 10.																	
1	*405*	*500*	*540*	*563*	*576*	*586*	*593*	*598*	*602*	*606*	*608*	*611*	*613*	*614*	*616*	*617*	*618*	*619*
2	98.5	99.0	99.2	99.2	99.3	99.3	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.4	99.4
3	34.1	30.8	29.5	28.7	28.2	27.9	27.7	27.5	27.3	27.2	27.1	27.1	27.0	26.9	26.9	26.8	26.8	26.8
4	21.2	18.0	16.7	16.0	15.5	15.2	15.0	14.8	14.7	14.5	14.4	14.4	14.3	14.2	14.2	14.2	14.1	14.1
5	16.3	13.3	12.1	11.4	11.0	10.7	10.5	10.3	10.2	10.1	9.96	9.89	9.82	9.77	9.72	9.68	9.64	9.61
6	13.7	10.9	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.79	7.72	7.66	7.60	7.56	7.52	7.48	7.45
7	12.2	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62	6.54	6.47	6.41	6.36	6.31	6.27	6.24	6.21
8	11.3	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81	5.73	5.67	5.61	5.56	5.52	5.48	5.44	5.41
9	10.6	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26	5.18	5.11	5.05	5.00	4.96	4.92	4.89	4.86
10	10.0	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85	4.77	4.71	4.65	4.60	4.56	4.52	4.49	4.46
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63	4.54	4.46	4.40	4.34	4.29	4.25	4.21	4.18	4.15
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30	4.22	4.16	4.10	4.05	4.01	3.97	3.94	3.91
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19	4.10	4.02	3.96	3.91	3.86	3.82	3.78	3.75	3.72
14	8.86	6.51	5.56	5.04	4.70	4.46	4.28	4.14	4.03	3.94	3.86	3.80	3.75	3.70	3.66	3.62	3.59	3.56
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89	3.80	3.73	3.67	3.61	3.56	3.52	3.49	3.45	3.42
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69	3.62	3.55	3.50	3.45	3.41	3.37	3.34	3.31
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68	3.59	3.52	3.46	3.40	3.35	3.31	3.27	3.24	3.21
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60	3.51	3.43	3.37	3.32	3.27	3.23	3.19	3.16	3.13
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43	3.36	3.30	3.24	3.19	3.15	3.12	3.08	3.05
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37	3.29	3.23	3.18	3.13	3.09	3.05	3.02	2.99
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40	3.31	3.24	3.17	3.12	3.07	3.03	2.99	2.96	2.93
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35	3.26	3.18	3.12	3.07	3.02	2.98	2.94	2.91	2.88
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30	3.21	3.14	3.07	3.02	2.97	2.93	2.89	2.86	2.83
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26	3.17	3.09	3.03	2.98	2.93	2.89	2.85	2.82	2.79
25	7.77	5.57	4.68	4.18	3.86	3.63	3.46	3.32	3.22	3.13	3.06	2.99	2.94	2.89	2.85	2.81	2.78	2.75
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18	3.09	3.02	2.96	2.90	2.86	2.82	2.78	2.74	2.72
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15	3.06	2.99	2.93	2.87	2.82	2.78	2.75	2.71	2.68
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12	3.03	2.96	2.90	2.84	2.79	2.75	2.72	2.68	2.65
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09	3.00	2.93	2.87	2.81	2.77	2.73	2.69	2.66	2.63
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98	2.91	2.84	2.79	2.74	2.70	2.66	2.63	2.60
32	7.50	5.34	4.46	3.97	3.65	3.43	3.26	3.13	3.02	2.93	2.86	2.80	2.74	2.70	2.66	2.62	2.58	2.55
34	7.44	5.29	4.42	3.93	3.61	3.39	3.22	3.09	2.98	2.89	2.82	2.76	2.70	2.66	2.62	2.58	2.55	2.51
36	7.40	5.25	4.38	3.89	3.57	3.35	3.18	3.05	2.95	2.86	2.79	2.72	2.67	2.62	2.58	2.54	2.51	2.48
38	7.35	5.21	4.34	3.86	3.54	3.32	3.15	3.02	2.92	2.83	2.75	2.69	2.64	2.59	2.55	2.51	2.48	2.45
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89	2.80	2.73	2.66	2.61	2.56	2.52	2.48	2.45	2.42
42	7.28	5.15	4.29	3.80	3.49	3.27	3.10	2.97	2.86	2.78	2.70	2.64	2.59	2.54	2.50	2.46	2.43	2.40
44	7.25	5.12	4.26	3.78	3.47	3.24	3.08	2.95	2.84	2.75	2.68	2.62	2.56	2.52	2.47	2.44	2.40	2.37
46	7.22	5.10	4.24	3.76	3.44	3.22	3.06	2.93	2.82	2.73	2.66	2.60	2.54	2.50	2.45	2.42	2.38	2.35
48	7.19	5.08	4.22	3.74	3.43	3.20	3.04	2.91	2.80	2.72	2.64	2.58	2.53	2.48	2.44	2.40	2.37	2.33
50	7.17	5.06	4.20	3.72	3.41	3.19	3.02	2.89	2.79	2.70	2.63	2.56	2.51	2.46	2.42	2.38	2.35	2.32
55	7.12	5.01	4.16	3.68	3.37	3.15	2.98	2.85	2.75	2.66	2.59	2.53	2.47	2.42	2.38	2.34	2.31	2.28
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63	2.56	2.50	2.44	2.39	2.35	2.31	2.28	2.25
65	7.04	4.95	4.10	3.62	3.31	3.09	2.93	2.80	2.69	2.61	2.53	2.47	2.42	2.37	2.33	2.29	2.26	2.23
70	7.01	4.92	4.08	3.60	3.29	3.07	2.91	2.78	2.67	2.59	2.51	2.45	2.40	2.35	2.31	2.27	2.23	2.20
80	6.96	4.88	4.04	3.56	3.26	3.04	2.87	2.74	2.64	2.55	2.48	2.42	2.36	2.31	2.27	2.23	2.20	2.17
90	6.93	4.85	4.01	3.54	3.23	3.01	2.84	2.72	2.61	2.52	2.45	2.39	2.33	2.29	2.24	2.21	2.17	2.14
100	6.90	4.82	3.98	3.51	3.21	2.99	2.82	2.69	2.59	2.50	2.43	2.37	2.31	2.26	2.22	2.19	2.15	2.12
125	6.84	4.78	3.94	3.47	3.17	2.95	2.79	2.66	2.55	2.47	2.39	2.33	2.28	2.23	2.19	2.15	2.11	2.08
150	6.81	4.75	3.92	3.45	3.14	2.92	2.76	2.63	2.53	2.44	2.37	2.31	2.25	2.20	2.16	2.12	2.09	2.06
200	6.76	4.71	3.88	3.41	3.11	2.89	2.73	2.60	2.50	2.41	2.34	2.27	2.22	2.17	2.13	2.09	2.06	2.02
300	6.72	4.68	3.85	3.38	3.08	2.86	2.70	2.57	2.47	2.38	2.31	2.24	2.19	2.14	2.10	2.06	2.03	1.99
500	6.69	4.65	3.82	3.36	3.05	2.84	2.68	2.55	2.44	2.36	2.28	2.22	2.17	2.12	2.07	2.04	2.00	1.97
1000	6.66	4.63	3.80	3.34	3.04	2.82	2.66	2.53	2.43	2.34	2.27	2.20	2.15	2.10	2.06	2.02	1.98	1.95
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41	2.32	2.25	2.18	2.13	2.08	2.04	2.00	1.97	1.93

Column header: Degrees of freedom for the numerator (ν_1)

Example: $P\{F_{.99;8,20} < 3.56\} = 99\%$.

$F_{.01;\nu_1,\nu_2} = 1/F_{.99;\nu_2,\nu_1}$. Example: $F_{.01;8,20} = 1/F_{.99;20,8} = 1/5.36 = 0.187$.

$F_{.01;\nu_1,\nu_2}$

Degrees of freedom for the numerator (ν_1)

Multiply the numbers of the first row ($\nu_2 = 1$) by 10.

19	20	22	24	26	28	30	35	40	45	50	60	80	100	200	500	∞	Degrees of freedom for the denominator (ν_2)
620	*621*	*622*	*623*	*624*	*625*	*626*	*628*	*629*	*630*	*630*	*631*	*633*	*633*	*635*	*636*	*637*	1
99.4	99.4	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	99.5	2
26.7	26.7	26.6	26.6	26.6	26.5	26.5	26.5	26.4	26.4	26.4	26.3	26.3	26.2	26.2	26.1	26.1	3
14.0	14.0	14.0	13.9	13.9	13.9	13.8	13.8	13.7	13.7	13.7	13.7	13.6	13.6	13.5	13.5	13.5	4
9.58	9.55	9.51	9.47	9.43	9.40	9.38	9.33	9.29	9.26	9.24	9.20	9.16	9.13	9.08	9.04	9.02	5
7.42	7.40	7.35	7.31	7.28	7.25	7.23	7.18	7.14	7.11	7.09	7.06	7.01	6.99	6.93	6.90	6.88	6
6.18	6.16	6.11	6.07	6.04	6.02	5.99	5.94	5.91	5.88	5.86	5.82	5.78	5.75	5.70	5.67	5.65	7
5.38	5.36	5.32	5.28	5.25	5.22	5.20	5.15	5.12	5.09	5.07	5.03	4.99	4.96	4.91	4.88	4.86	8
4.83	4.81	4.77	4.73	4.70	4.67	4.65	4.60	4.57	4.54	4.52	4.48	4.44	4.42	4.36	4.33	4.31	9
4.43	4.41	4.36	4.33	4.30	4.27	4.25	4.20	4.17	4.14	4.12	4.08	4.04	4.01	3.96	3.93	3.91	10
4.12	4.10	4.06	4.02	3.99	3.96	3.94	3.89	3.86	3.83	3.81	3.78	3.73	3.71	3.66	3.62	3.60	11
3.88	3.86	3.82	3.78	3.75	3.72	3.70	3.65	3.62	3.59	3.57	3.54	3.49	3.47	3.41	3.38	3.36	12
3.69	3.66	3.62	3.59	3.56	3.53	3.51	3.46	3.43	3.40	3.38	3.34	3.30	3.27	3.22	3.19	3.17	13
3.53	3.51	3.46	3.43	3.40	3.37	3.35	3.30	3.27	3.24	3.22	3.18	3.14	3.11	3.06	3.03	3.00	14
3.40	3.37	3.33	3.29	3.26	3.24	3.21	3.17	3.13	3.10	3.08	3.05	3.00	2.98	2.92	2.89	2.87	15
3.28	3.26	3.22	3.18	3.15	3.12	3.10	3.05	3.02	2.99	2.97	2.93	2.89	2.86	2.81	2.78	2.75	16
3.18	3.16	3.12	3.08	3.05	3.03	3.00	2.96	2.92	2.89	2.87	2.83	2.79	2.76	2.71	2.68	2.65	17
3.10	3.08	3.03	3.00	2.97	2.94	2.92	2.87	2.84	2.81	2.78	2.75	2.70	2.68	2.62	2.59	2.57	18
3.03	3.00	2.96	2.92	2.89	2.87	2.84	2.80	2.76	2.73	2.71	2.67	2.63	2.60	2.55	2.51	2.49	19
2.96	2.94	2.90	2.86	2.83	2.80	2.78	2.73	2.69	2.67	2.64	2.61	2.56	2.54	2.48	2.44	2.42	20
2.90	2.88	2.84	2.80	2.77	2.74	2.72	2.67	2.64	2.61	2.58	2.55	2.50	2.48	2.42	2.38	2.36	21
2.85	2.83	2.78	2.75	2.72	2.69	2.67	2.62	2.58	2.55	2.53	2.50	2.45	2.42	2.36	2.33	2.31	22
2.80	2.78	2.74	2.70	2.67	2.64	2.62	2.57	2.54	2.51	2.48	2.45	2.40	2.37	2.32	2.28	2.26	23
2.76	2.74	2.70	2.66	2.63	2.60	2.58	2.53	2.49	2.46	2.44	2.40	2.36	2.33	2.27	2.24	2.21	24
2.72	2.70	2.66	2.62	2.59	2.56	2.54	2.49	2.45	2.42	2.40	2.36	2.32	2.29	2.23	2.19	2.17	25
2.69	2.66	2.62	2.58	2.55	2.53	2.50	2.45	2.42	2.39	2.36	2.33	2.28	2.25	2.19	2.16	2.13	26
2.66	2.63	2.59	2.55	2.52	2.49	2.47	2.42	2.38	2.35	2.33	2.29	2.25	2.22	2.16	2.12	2.10	27
2.63	2.60	2.56	2.52	2.49	2.46	2.44	2.39	2.35	2.32	2.30	2.26	2.22	2.19	2.13	2.09	2.06	28
2.60	2.57	2.53	2.49	2.46	2.44	2.41	2.36	2.33	2.30	2.27	2.23	2.19	2.16	2.10	2.06	2.03	29
2.57	2.55	2.51	2.47	2.44	2.41	2.39	2.34	2.30	2.27	2.25	2.21	2.16	2.13	2.07	2.03	2.01	30
2.53	2.50	2.46	2.42	2.39	2.36	2.34	2.29	2.25	2.22	2.20	2.16	2.11	2.08	2.02	1.98	1.96	32
2.49	2.46	2.42	2.38	2.35	2.32	2.30	2.25	2.21	2.18	2.16	2.12	2.07	2.04	1.98	1.94	1.91	34
2.45	2.43	2.38	2.35	2.32	2.29	2.26	2.21	2.17	2.14	2.12	2.08	2.03	2.00	1.94	1.90	1.87	36
2.42	2.40	2.35	2.32	2.28	2.26	2.23	2.18	2.14	2.11	2.09	2.05	2.00	1.97	1.90	1.86	1.84	38
2.39	2.37	2.33	2.29	2.26	2.23	2.20	2.15	2.11	2.08	2.06	2.02	1.97	1.94	1.87	1.83	1.80	40
2.37	2.34	2.30	2.26	2.23	2.20	2.18	2.13	2.09	2.06	2.03	1.99	1.94	1.91	1.85	1.80	1.78	42
2.35	2.32	2.28	2.24	2.21	2.18	2.15	2.10	2.06	2.03	2.01	1.97	1.92	1.89	1.82	1.78	1.75	44
2.33	2.30	2.26	2.22	2.19	2.16	2.13	2.08	2.04	2.01	1.99	1.95	1.90	1.86	1.80	1.75	1.73	46
2.31	2.28	2.24	2.20	2.17	2.14	2.12	2.06	2.02	1.99	1.97	1.93	1.88	1.84	1.78	1.73	1.70	48
2.29	2.27	2.22	2.18	2.15	2.12	2.10	2.05	2.01	1.97	1.95	1.91	1.86	1.82	1.76	1.71	1.68	50
2.25	2.23	2.18	2.15	2.11	2.08	2.06	2.01	1.97	1.93	1.91	1.87	1.81	1.78	1.71	1.67	1.64	55
2.22	2.20	2.15	2.12	2.08	2.05	2.03	1.98	1.94	1.90	1.88	1.84	1.78	1.75	1.68	1.63	1.60	60
2.20	2.17	2.13	2.09	2.06	2.03	2.00	1.95	1.91	1.88	1.85	1.81	1.75	1.72	1.65	1.60	1.57	65
2.18	2.15	2.11	2.07	2.03	2.01	1.98	1.93	1.89	1.85	1.83	1.78	1.73	1.70	1.62	1.57	1.54	70
2.14	2.12	2.07	2.03	2.00	1.97	1.94	1.89	1.85	1.81	1.79	1.75	1.69	1.66	1.58	1.53	1.49	80
2.11	2.09	2.04	2.00	1.97	1.94	1.92	1.86	1.82	1.79	1.76	1.72	1.66	1.62	1.54	1.49	1.46	90
2.09	2.07	2.02	1.98	1.94	1.92	1.89	1.84	1.80	1.76	1.73	1.69	1.63	1.60	1.52	1.47	1.43	100
2.05	2.03	1.98	1.94	1.91	1.88	1.85	1.80	1.76	1.72	1.69	1.65	1.59	1.55	1.47	1.41	1.37	125
2.03	2.00	1.96	1.92	1.88	1.85	1.83	1.77	1.73	1.69	1.66	1.62	1.56	1.52	1.43	1.38	1.33	150
2.00	1.97	1.93	1.89	1.85	1.82	1.79	1.74	1.69	1.66	1.63	1.58	1.52	1.48	1.39	1.33	1.28	200
1.97	1.94	1.89	1.85	1.82	1.79	1.76	1.71	1.66	1.62	1.59	1.55	1.48	1.44	1.35	1.28	1.22	300
1.94	1.92	1.87	1.83	1.79	1.76	1.74	1.68	1.63	1.60	1.56	1.52	1.45	1.41	1.31	1.23	1.16	500
1.92	1.90	1.85	1.81	1.77	1.74	1.72	1.66	1.61	1.57	1.54	1.50	1.43	1.38	1.28	1.19	1.11	1000
1.90	1.88	1.83	1.79	1.76	1.72	1.70	1.64	1.59	1.55	1.52	1.47	1.40	1.36	1.25	1.15	1.00	∞

Approximate formula for ν_1 and ν_2 larger than 30: $\log_{10} F_{.01;\nu_1,\nu_2} \simeq \dfrac{2.0206}{\sqrt{h} - 1.40} - 1.073\left(\dfrac{1}{\nu_1} - \dfrac{1}{\nu_2}\right)$, where $\dfrac{1}{h} = \dfrac{1}{2}\left(\dfrac{1}{\nu_1} + \dfrac{1}{\nu_2}\right)$.

Degrees of freedom for the denominator (ν_2)	Degrees of freedom for the numerator (ν_1) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Multiply the numbers of the first row (ν_2 = 1) by 100.																	
1	*162*	*200*	*216*	*225*	*231*	*234*	*237*	*239*	*241*	*242*	*243*	*244*	*245*	*246*	*246*	*247*	*247*	*248*
2	198	199	199	199	199	199	199	199	199	199	199	199	199	199	199	199	199	199
3	55.6	49.8	47.5	46.2	45.4	44.8	44.4	44.1	43.9	43.7	43.5	43.4	43.3	43.2	43.1	43.0	42.9	42.9
4	31.3	26.3	24.3	23.2	22.5	22.0	21.6	21.4	21.1	21.0	20.8	20.7	20.6	20.5	20.4	20.4	20.3	20.3
5	22.8	18.3	16.5	15.6	14.9	14.5	14.2	14.0	13.8	13.6	13.5	13.4	13.3	13.2	13.1	13.1	13.0	13.0
6	18.6	14.5	12.9	12.0	11.5	11.1	10.8	10.6	10.4	10.2	10.1	10.0	9.95	9.88	9.81	9.76	9.71	9.66
7	16.2	12.4	10.9	10.0	9.52	9.16	8.89	8.68	8.51	8.38	8.27	8.18	8.10	8.03	7.97	7.93	7.87	7.83
8	14.7	11.0	9.60	8.81	8.30	7.95	7.69	7.50	7.34	7.21	7.10	7.01	6.94	6.87	6.81	6.76	6.72	6.68
9	13.6	10.1	8.72	7.96	7.47	7.13	6.88	6.69	6.54	6.42	6.31	6.23	6.15	6.09	6.03	5.98	5.94	5.90
10	12.8	9.43	8.08	7.34	6.87	6.54	6.30	6.12	5.97	5.85	5.75	5.66	5.59	5.53	5.47	5.42	5.38	5.34
11	12.2	8.91	7.60	6.88	6.42	6.10	5.86	5.68	5.54	5.42	5.32	5.24	5.16	5.10	5.05	5.00	4.96	4.92
12	11.8	8.51	7.23	6.52	6.07	5.76	5.52	5.35	5.20	5.09	4.99	4.91	4.84	4.77	4.72	4.67	4.63	4.59
13	11.4	8.19	6.93	6.23	5.79	5.48	5.25	5.08	4.94	4.82	4.72	4.64	4.57	4.51	4.46	4.41	4.37	4.33
14	11.1	7.92	6.68	6.00	5.56	5.26	5.03	4.86	4.72	4.60	4.51	4.43	4.36	4.30	4.25	4.20	4.16	4.12
15	10.8	7.70	6.48	5.80	5.37	5.07	4.85	4.67	4.54	4.42	4.33	4.25	4.18	4.12	4.07	4.02	3.98	3.95
16	10.6	7.51	6.30	5.64	5.21	4.91	4.69	4.52	4.38	4.27	4.18	4.10	4.03	3.97	3.92	3.87	3.83	3.80
17	10.4	7.35	6.16	5.50	5.07	4.78	4.56	4.39	4.25	4.14	4.05	3.97	3.90	3.84	3.79	3.75	3.71	3.67
18	10.2	7.21	6.03	5.37	4.96	4.66	4.44	4.28	4.14	4.03	3.94	3.86	3.79	3.73	3.68	3.64	3.60	3.56
19	10.1	7.09	5.92	5.27	4.85	4.56	4.34	4.18	4.04	3.93	3.84	3.76	3.70	3.64	3.59	3.54	3.50	3.46
20	9.94	6.99	5.82	5.17	4.76	4.47	4.26	4.09	3.96	3.85	3.76	3.68	3.61	3.55	3.50	3.46	3.42	3.38
21	9.83	6.89	5.73	5.09	4.68	4.39	4.18	4.01	3.88	3.77	3.68	3.60	3.54	3.48	3.43	3.38	3.34	3.31
22	9.73	6.81	5.65	5.02	4.61	4.32	4.11	3.94	3.81	3.70	3.61	3.54	3.47	3.41	3.36	3.31	3.27	3.24
23	9.63	6.73	5.58	4.95	4.54	4.26	4.05	3.88	3.75	3.64	3.55	3.47	3.41	3.35	3.30	3.25	3.21	3.18
24	9.55	6.66	5.52	4.89	4.49	4.20	3.99	3.83	3.69	3.59	3.50	3.42	3.35	3.30	3.25	3.20	3.16	3.12
25	9.48	6.60	5.46	4.84	4.43	4.15	3.94	3.78	3.64	3.54	3.45	3.37	3.30	3.26	3.20	3.15	3.11	3.08
26	9.41	6.54	5.41	4.79	4.38	4.10	3.89	3.73	3.60	3.49	3.40	3.33	3.26	3.20	3.15	3.11	3.07	3.03
27	9.34	6.49	5.36	4.74	4.34	4.06	3.85	3.69	3.56	3.45	3.36	3.28	3.22	3.16	3.11	3.07	3.03	2.99
28	9.28	6.44	5.32	4.70	4.30	4.02	3.81	3.65	3.52	3.41	3.32	3.25	3.18	3.12	3.07	3.03	2.99	2.95
29	9.2[illegible]	6.40	5.28	4.66	4.26	3.98	3.77	3.61	3.48	3.38	3.29	3.21	3.15	3.09	3.04	2.99	2.95	2.92
30	9.18	6.35	5.24	4.62	4.23	3.95	3.74	3.58	3.45	3.34	3.25	3.18	3.11	3.06	3.01	2.96	2.92	2.89
32	9.09	6.28	5.17	4.56	4.17	3.89	3.68	3.52	3.39	3.29	3.20	3.12	3.06	3.00	2.95	2.90	2.86	2.83
34	9.01	6.22	5.11	4.50	4.11	3.84	3.63	3.47	3.34	3.24	3.15	3.07	3.01	2.95	2.90	2.85	2.81	2.78
36	8.94	6.16	5.06	4.46	4.06	3.79	3.58	3.42	3.30	3.19	3.10	3.03	2.96	2.90	2.85	2.81	2.77	2.73
38	8.88	6.11	5.02	4.41	4.02	3.75	3.54	3.39	3.25	3.15	3.06	2.99	2.92	2.87	2.82	2.77	2.73	2.70
40	8.83	6.07	4.98	4.37	3.99	3.71	3.51	3.35	3.22	3.12	3.03	2.95	2.89	2.83	2.78	2.74	2.70	2.66
42	8.78	6.03	4.94	4.34	3.95	3.68	3.48	3.32	3.19	3.09	3.00	2.92	2.86	2.80	2.75	2.71	2.67	2.63
44	8.74	5.99	4.91	4.31	3.92	3.65	3.45	3.29	3.16	3.06	2.97	2.89	2.83	2.77	2.72	2.68	2.64	2.60
46	8.70	5.96	4.88	4.28	3.90	3.62	3.42	3.26	3.14	3.03	2.94	2.87	2.80	2.75	2.70	2.65	2.61	2.58
48	8.66	5.93	4.85	4.25	3.87	3.60	3.40	3.24	3.11	3.01	2.92	2.85	2.78	2.72	2.67	2.63	2.59	2.55
50	8.63	5.90	4.83	4.23	3.85	3.58	3.38	3.22	3.09	2.99	2.90	2.82	2.76	2.70	2.65	2.61	2.57	2.53
55	8.55	5.84	4.77	4.18	3.80	3.53	3.33	3.17	3.05	2.94	2.85	2.78	2.71	2.66	2.61	2.56	2.52	2.49
60	8.49	5.80	4.73	4.14	3.76	3.49	3.29	3.13	3.01	2.90	2.82	2.74	2.68	2.62	2.57	2.53	2.49	2.45
65	8.44	5.75	4.68	4.11	3.73	3.46	3.26	3.10	2.98	2.87	2.79	2.71	2.65	2.59	2.54	2.49	2.45	2.42
70	8.40	5.72	4.65	4.08	3.70	3.43	3.23	3.08	2.95	2.85	2.76	2.68	2.62	2.56	2.51	2.47	2.43	2.39
80	8.33	5.67	4.61	4.03	3.65	3.39	3.19	3.03	2.91	2.80	2.72	2.64	2.58	2.52	2.47	2.43	2.39	2.35
90	8.28	5.62	4.57	3.99	3.62	3.35	3.15	3.00	2.87	2.77	2.68	2.61	2.54	2.49	2.44	2.39	2.35	2.32
100	8.24	5.59	4.54	3.96	3.59	3.33	3.13	2.97	2.85	2.74	2.66	2.58	2.52	2.46	2.41	2.37	2.33	2.29
125	8.17	5.53	4.49	3.91	3.54	3.28	3.08	2.93	2.80	2.70	2.61	2.54	2.47	2.42	2.37	2.32	2.28	2.24
150	8.12	5.49	4.45	3.88	3.51	3.25	3.05	2.89	2.77	2.67	2.58	2.51	2.44	2.38	2.33	2.29	2.25	2.21
200	8.06	5.44	4.41	3.84	3.47	3.21	3.01	2.85	2.73	2.63	2.54	2.47	2.40	2.35	2.30	2.25	2.21	2.18
300	8.00	5.39	4.37	3.80	3.43	3.17	2.97	2.81	2.69	2.59	2.51	2.43	2.37	2.31	2.26	2.21	2.17	2.14
500	7.95	5.36	4.33	3.76	3.40	3.14	2.94	2.79	2.66	2.56	2.48	2.40	2.34	2.28	2.23	2.19	2.14	2.11
1000	7.92	5.33	4.31	3.74	3.37	3.11	2.92	2.77	2.64	2.54	2.45	2.38	2.32	2.26	2.21	2.16	2.12	2.09
∞	7.88	5.30	4.28	3.72	3.35	3.09	2.90	2.74	2.62	2.52	2.43	2.36	2.29	2.24	2.19	2.14	2.10	2.06

Example: $P\{F_{.995;3,30} < 4.09\} = 99.5\%$.

$F_{.005;\nu_1,\nu_2} = 1/F_{.995;\nu_2,\nu_1}$. Example: $F_{.005;3,30} = 1/F_{.995;30,3} = 1/6.61 = 0.151$.

$F_{.005;\nu_1,\nu_2}$

Degrees of freedom for the numerator (ν_1)

Multiply the numbers of the first row ($\nu_2 = 1$) by 100.

10	20	22	24	26	28	30	35	40	45	50	60	80	100	200	500	∞	Degrees of freedom for the denominator (ν_2)
248	*248*	*249*	*249*	*250*	*250*	*250*	*251*	*251*	*252*	*252*	*253*	*253*	*253*	*254*	*254*	*255*	1
199	199	199	199	199	199	199	199	199	199	199	199	199	199	199	200	200	2
42.8	42.8	42.7	42.6	42.6	42.5	42.5	42.4	42.3	42.3	42.2	42.1	42.1	42.0	41.9	41.9	41.8	3
20.2	20.2	20.1	20.0	20.0	19.9	19.9	19.8	19.8	19.7	19.7	19.6	19.5	19.5	19.4	19.4	19.3	4
12.9	12.9	12.8	12.8	12.7	12.7	12.7	12.6	12.5	12.5	12.5	12.4	12.3	12.3	12.2	12.2	12.1	5
9.62	9.59	9.53	9.47	9.43	9.39	9.36	9.29	9.24	9.20	9.17	9.12	9.06	9.03	8.95	8.91	8.88	6
7.79	7.75	7.69	7.64	7.60	7.57	7.53	7.47	7.42	7.38	7.35	7.31	7.25	7.22	7.15	7.10	7.08	7
6.64	6.61	6.55	6.50	6.46	6.43	6.40	6.33	6.29	6.25	6.22	6.18	6.12	6.09	6.02	5.98	5.95	8
5.86	5.83	5.78	5.73	5.69	5.65	5.62	5.56	5.52	5.48	5.45	5.41	5.36	5.32	5.26	5.21	5.19	9
5.30	5.27	5.22	5.17	5.13	5.10	5.07	5.01	4.97	4.93	4.90	4.86	4.80	4.77	4.71	4.67	4.64	10
4.89	4.86	4.80	4.76	4.72	4.68	4.65	4.60	4.55	4.52	4.49	4.44	4.39	4.36	4.29	4.25	4.23	11
4.56	4.53	4.48	4.43	4.39	4.36	4.33	4.27	4.23	4.19	4.17	4.12	4.07	4.04	3.97	3.93	3.90	12
4.30	4.27	4.22	4.17	4.13	4.10	4.07	4.01	3.97	3.94	3.91	3.87	3.81	3.78	3.71	3.67	3.65	13
4.09	4.06	4.01	3.96	3.92	3.89	3.86	3.80	3.76	3.73	3.70	3.66	3.60	3.57	3.50	3.46	3.44	14
3.91	3.88	3.83	3.79	3.75	3.72	3.69	3.63	3.58	3.55	3.52	3.48	3.43	3.39	3.33	3.29	3.26	15
3.76	3.73	3.68	3.64	3.60	3.57	3.54	3.48	3.44	3.40	3.37	3.33	3.28	3.25	3.18	3.14	3.11	16
3.64	3.61	3.56	3.51	3.47	3.44	3.41	3.35	3.31	3.28	3.25	3.21	3.15	3.12	3.05	3.01	2.98	17
3.53	3.50	3.45	3.40	3.36	3.33	3.30	3.25	3.20	3.17	3.14	3.10	3.04	3.01	2.94	2.90	2.87	18
3.43	3.40	3.35	3.31	3.27	3.24	3.21	3.15	3.11	3.07	3.04	3.00	2.95	2.91	2.85	2.80	2.78	19
3.35	3.32	3.27	3.22	3.18	3.15	3.12	3.07	3.02	2.99	2.96	2.92	2.86	2.83	2.76	2.72	2.69	20
3.27	3.24	3.19	3.15	3.11	3.08	3.05	2.99	2.95	2.91	2.88	2.84	2.78	2.75	2.68	2.64	2.61	21
3.20	3.18	3.12	3.08	3.04	3.01	2.98	2.92	2.88	2.84	2.82	2.77	2.72	2.69	2.62	2.57	2.55	22
3.15	3.12	3.06	3.02	2.98	2.95	2.92	2.86	2.82	2.78	2.76	2.71	2.66	2.62	2.56	2.51	2.48	23
3.09	3.06	3.01	2.97	2.93	2.90	2.87	2.81	2.77	2.73	2.70	2.66	2.60	2.57	2.50	2.46	2.43	24
3.04	3.01	2.96	2.92	2.88	2.85	2.82	2.76	2.72	2.68	2.65	2.61	2.55	2.52	2.45	2.41	2.38	25
3.00	2.97	2.92	2.87	2.83	2.80	2.77	2.72	2.67	2.64	2.61	2.56	2.51	2.47	2.40	2.36	2.33	26
2.96	2.93	2.88	2.83	2.79	2.76	2.73	2.67	2.63	2.59	2.57	2.52	2.47	2.43	2.36	2.32	2.29	27
2.92	2.89	2.84	2.79	2.76	2.72	2.69	2.64	2.59	2.56	2.53	2.48	2.43	2.39	2.32	2.28	2.25	28
2.88	2.86	2.80	2.76	2.72	2.69	2.66	2.60	2.56	2.52	2.49	2.45	2.39	2.36	2.28	2.24	2.21	29
2.85	2.82	2.77	2.73	2.69	2.66	2.63	2.57	2.52	2.49	2.46	2.42	2.36	2.32	2.25	2.21	2.18	30
2.80	2.77	2.71	2.67	2.63	2.60	2.57	2.51	2.47	2.43	2.40	2.36	2.30	2.26	2.19	2.15	2.11	32
2.75	2.72	2.66	2.62	2.58	2.55	2.52	2.46	2.42	2.38	2.35	2.30	2.25	2.21	2.14	2.09	2.06	34
2.70	2.67	2.62	2.58	2.54	2.50	2.48	2.42	2.37	2.33	2.30	2.26	2.20	2.17	2.09	2.04	2.01	36
2.66	2.63	2.58	2.54	2.50	2.47	2.44	2.38	2.33	2.29	2.27	2.22	2.16	2.12	2.05	2.00	1.97	38
2.63	2.60	2.55	2.50	2.46	2.43	2.40	2.34	2.30	2.26	2.23	2.18	2.12	2.09	2.01	1.96	1.93	40
2.60	2.57	2.52	2.47	2.43	2.40	2.37	2.31	2.26	2.23	2.20	2.15	2.09	2.06	1.98	1.93	1.90	42
2.57	2.54	2.49	2.44	2.40	2.37	2.34	2.28	2.24	2.20	2.17	2.12	2.06	2.03	1.95	1.90	1.87	44
2.54	2.51	2.46	2.42	2.38	2.34	2.32	2.26	2.21	2.17	2.14	2.10	2.04	2.00	1.92	1.87	1.84	46
2.52	2.49	2.44	2.39	2.36	2.32	2.29	2.23	2.19	2.15	2.12	2.07	2.01	1.97	1.89	1.84	1.81	48
2.50	2.47	2.42	2.37	2.33	2.30	2.27	2.21	2.16	2.13	2.10	2.05	1.99	1.95	1.87	1.82	1.79	50
2.45	2.42	2.37	2.33	2.29	2.26	2.23	2.16	2.12	2.08	2.05	2.00	1.94	1.90	1.82	1.77	1.73	55
2.42	2.39	2.33	2.29	2.25	2.22	2.19	2.13	2.08	2.04	2.01	1.96	1.90	1.86	1.78	1.73	1.69	60
2.39	2.36	2.30	2.26	2.22	2.19	2.16	2.09	2.05	2.01	1.98	1.93	1.87	1.83	1.74	1.69	1.65	65
2.36	2.33	2.28	2.23	2.19	2.16	2.13	2.07	2.02	1.98	1.95	1.90	1.84	1.80	1.71	1.66	1.62	70
2.32	2.29	2.23	2.19	2.15	2.11	2.08	2.02	1.97	1.93	1.90	1.85	1.79	1.75	1.66	1.60	1.56	80
2.28	2.25	2.20	2.15	2.12	2.08	2.05	1.99	1.94	1.90	1.87	1.82	1.75	1.71	1.62	1.56	1.52	90
2.26	2.23	2.17	2.13	2.09	2.05	2.02	1.96	1.91	1.87	1.84	1.79	1.72	1.68	1.59	1.53	1.49	100
2.21	2.18	2.13	2.08	2.04	2.01	1.98	1.91	1.86	1.82	1.79	1.74	1.67	1.63	1.53	1.47	1.42	125
2.18	2.15	2.10	2.05	2.01	1.98	1.94	1.88	1.83	1.79	1.76	1.70	1.63	1.59	1.49	1.42	1.37	150
2.14	2.11	2.06	2.01	1.97	1.94	1.91	1.84	1.79	1.75	1.71	1.66	1.59	1.54	1.44	1.37	1.31	200
2.10	2.07	2.02	1.97	1.93	1.90	1.87	1.80	1.75	1.71	1.67	1.61	1.54	1.50	1.39	1.31	1.25	300
2.07	2.04	1.99	1.94	1.90	1.87	1.84	1.77	1.72	1.67	1.64	1.58	1.51	1.46	1.35	1.26	1.18	500
2.05	2.02	1.97	1.92	1.88	1.84	1.81	1.75	1.69	1.65	1.61	1.56	1.48	1.43	1.31	1.22	1.13	1000
2.03	2.00	1.95	1.90	1.86	1.82	1.79	1.72	1.67	1.63	1.59	1.53	1.45	1.40	1.28	1.17	1.00	∞

Approximate formula for ν_1 and ν_2 larger than 30: $\log_{10} F_{.005;\nu_1,\nu_2} \simeq \dfrac{2.2373}{\sqrt{h - 1.61}} - 1.250\left(\dfrac{1}{\nu_1} - \dfrac{1}{\nu_2}\right)$, where $\dfrac{1}{h} = \dfrac{1}{2}\left(\dfrac{1}{\nu_1} + \dfrac{1}{\nu_2}\right)$.

TABLE 13.27 *(Continued)* **0.1 PERCENTAGE POINT OF THE F DISTRIBUTION**

Table of $F_{.001;\nu_1,\nu_2}$

Degrees of freedom for the denominator (ν_2)	1	2	3	4	5	6	7	8	9	10	15	20	30	50	100	200	500	∞
	Multiply the numbers of the first row ($\nu_2 = 1$) by 1000.																	
1	*405*	*500*	*540*	*563*	*576*	*586*	*593*	*598*	*602*	*606*	*616*	*621*	*626*	*630*	*633*	*635*	*636*	*637*
2	998	999	999	999	999	999	999	999	999	999	999	999	999	999	999	999	999	999
3	168	148	141	137	135	133	132	131	130	129	127	126	125	125	124	124	124	124
4	74.1	61.2	56.2	53.4	51.7	50.5	49.7	49.0	48.5	48.0	46.8	46.1	45.4	44.9	44.5	44.3	44.1	44.0
5	47.0	36.6	33.2	31.1	29.8	28.8	28.2	27.6	27.2	26.9	25.9	25.4	24.9	24.4	24.1	23.9	23.8	23.8
6	35.5	27.0	23.7	21.9	20.8	20.0	19.5	19.0	18.7	18.4	17.6	17.1	16.7	16.3	16.0	15.9	15.8	15.8
7	29.2	21.7	18.8	17.2	16.2	15.5	15.0	14.6	14.3	14.1	13.3	12.9	12.5	12.2	11.9	11.8	11.7	11.7
8	25.4	18.5	15.8	14.4	13.5	12.9	12.4	12.0	11.8	11.5	10.8	10.5	10.1	9.80	9.57	9.46	9.39	9.34
9	22.9	16.4	13.9	12.6	11.7	11.1	10.7	10.4	10.1	9.89	9.24	8.90	8.55	8.26	8.04	7.93	7.86	7.81
10	21.0	14.9	12.6	11.3	10.5	9.92	9.52	9.20	8.96	8.75	8.13	7.80	7.47	7.19	6.98	6.87	6.81	6.76
11	19.7	13.8	11.6	10.4	9.58	9.05	8.66	8.35	8.12	7.92	7.32	7.01	6.68	6.41	6.21	6.10	6.04	6.00
12	18.6	13.0	10.8	9.63	8.89	8.38	8.00	7.71	7.48	7.29	6.71	6.40	6.09	5.83	5.63	5.52	5.46	5.42
13	17.8	12.3	10.2	9.07	8.35	7.86	7.49	7.21	6.98	6.80	6.23	5.93	5.63	5.37	5.17	5.07	5.01	4.97
14	17.1	11.8	9.73	8.62	7.92	7.43	7.08	6.80	6.58	6.40	5.85	5.56	5.25	5.00	4.80	4.70	4.64	4.60
15	16.6	11.3	9.34	8.25	7.57	7.09	6.74	6.47	6.26	6.08	5.53	5.25	4.95	4.70	4.51	4.41	4.35	4.31
16	16.1	11.0	9.00	7.94	7.27	6.81	6.46	6.19	5.98	5.81	5.27	4.99	4.70	4.45	4.26	4.16	4.10	4.06
17	15.7	10.7	8.73	7.68	7.02	6.56	6.22	5.96	5.75	5.58	5.05	4.78	4.48	4.24	4.05	3.95	3.89	3.85
18	15.4	10.4	8.49	7.46	6.81	6.35	6.02	5.76	5.56	5.39	4.87	4.59	4.30	4.06	3.87	3.77	3.71	3.67
19	15.1	10.2	8.28	7.26	6.61	6.18	5.84	5.59	5.39	5.22	4.70	4.43	4.14	3.90	3.71	3.61	3.55	3.51
20	14.8	9.95	8.10	7.10	6.46	6.02	5.69	5.44	5.24	5.08	4.56	4.29	4.01	3.77	3.58	3.48	3.42	3.38
22	14.4	9.61	7.80	6.81	6.19	5.76	5.44	5.19	4.99	4.83	4.32	4.06	3.77	3.53	3.34	3.25	3.19	3.15
24	14.0	9.34	7.55	6.59	5.98	5.55	5.23	4.99	4.80	4.61	4.14	3.87	3.59	3.35	3.16	3.07	3.01	2.97
26	13.7	9.12	7.36	6.41	5.80	5.38	5.07	4.83	4.64	4.48	3.99	3.72	3.45	3.20	3.01	2.92	2.86	2.82
28	13.5	8.93	7.19	6.25	5.66	5.24	4.93	4.69	4.50	4.35	3.86	3.60	3.32	3.08	2.89	2.79	2.73	2.70
30	13.3	8.77	7.05	6.12	5.53	5.12	4.82	4.58	4.39	4.24	3.75	3.49	3.22	2.98	2.79	2.69	2.63	2.59
40	12.6	8.25	6.60	5.70	5.13	4.73	4.43	4.21	4.02	3.87	3.40	3.15	2.87	2.64	2.44	2.34	2.28	2.23
50	12.2	7.95	6.34	5.46	4.90	4.51	4.22	4.00	3.82	3.67	3.20	2.95	2.68	2.44	2.24	2.14	2.07	2.03
60	12.0	7.76	6.17	5.31	4.76	4.37	4.09	3.87	3.69	3.54	3.08	2.83	2.56	2.31	2.11	2.01	1.93	1.89
80	11.7	7.54	5.97	5.13	4.58	4.21	3.92	3.70	3.53	3.39	2.93	2.68	2.40	2.16	1.95	1.84	1.77	1.72
100	11.5	7.41	5.85	5.01	4.48	4.11	3.83	3.61	3.44	3.30	2.84	2.59	2.32	2.07	1.87	1.75	1.68	1.62
200	11.2	7.15	5.64	4.81	4.29	3.92	3.65	3.43	3.26	3.12	2.67	2.42	2.15	1.90	1.68	1.55	1.46	1.39
500	11.0	7.01	5.51	4.69	4.18	3.82	3.54	3.33	3.16	3.02	2.58	2.33	2.05	1.80	1.57	1.43	1.32	1.23
∞	10.8	6.91	5.42	4.62	4.10	3.74	3.47	3.27	3.10	2.96	2.51	2.27	1.99	1.73	1.49	1.34	1.21	1.00

Column heading: Degrees of freedom for the numerator (ν_1)

Example: $P\{F_{.001,8,20} < 5.44\} = 99.9\%$.

$F_{.999,\nu_1,\nu_2} = 1/F_{.001;\nu_2,\nu_1}$. Example: $F_{.999,8,20} = 1/F_{.001,20,8} = 1/10.5 = 0.095$.

Approximate formula for ν_1 and ν_2 larger than 30: $\log_{10} F_{.001;\nu_1,\nu_2} \simeq \dfrac{2.6841}{\sqrt{h - 2.09}} - 1.672\left(\dfrac{1}{\nu_1} - \dfrac{1}{\nu_2}\right)$, where $\dfrac{1}{h} = \dfrac{1}{2}\left(\dfrac{1}{\nu_1} + \dfrac{1}{\nu_2}\right)$.

4.11 PROBLEMS OF ESTIMATION: CONFIDENCE INTERVALS

A common statistical problem is to estimate parameters on the basis of a sample. A single number (e.g., a sample mean) is occasionally adequate but usually it is desirable to give an indication of the reliability of these estimates and present an interval that may be said to be "likely" to contain the true value. More precisely, an interval is said to be a confidence interval of size $(1 - \alpha)$ if in the long run $100(1 - \alpha)\%$ of intervals constructed in this way contain the true value.

For example, suppose we are interested in estimating the mean breaking strength of 1040 carbon steel; ten specimens are tested. One possibility would

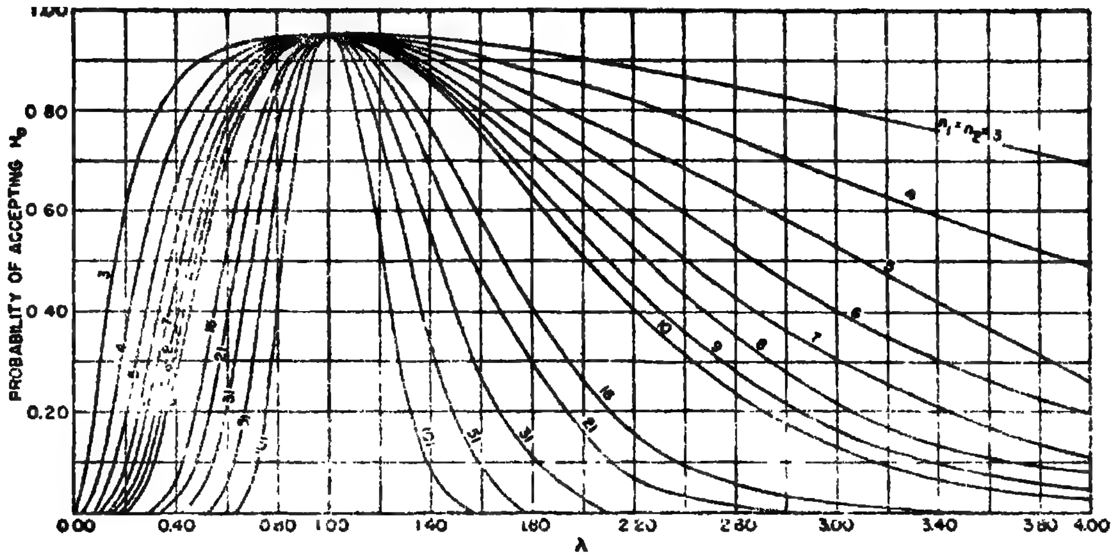
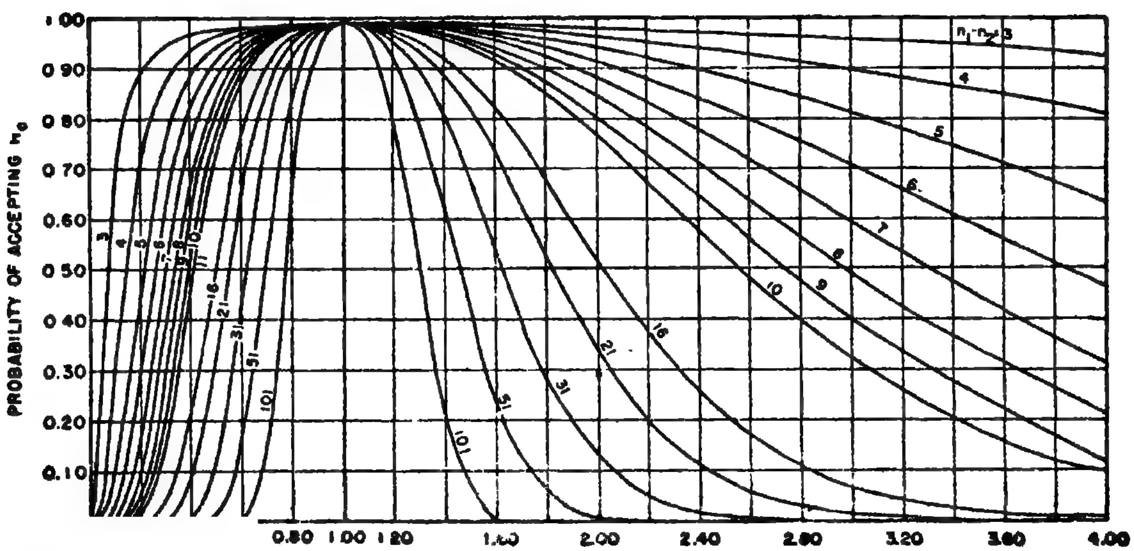
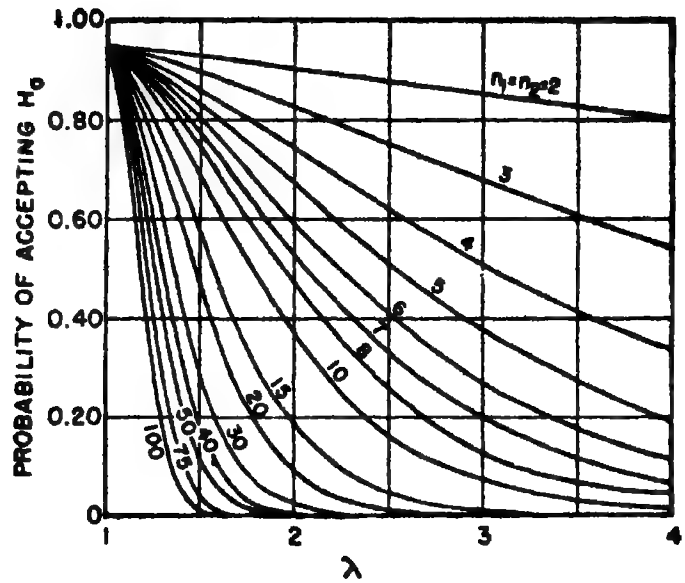


FIG. 13.39 OPERATING CHARACTERISTICS OF THE TWO-SIDED F TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.05.

FIG. 13.40 OPERATING CHARACTERISTICS OF THE TWO-SIDED F TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.01.





Reproduced by permission from "Operating Characteristics for the Common Statistical Tests of Significance" by Charles D. Ferris, Frank E. Grubbs, Chalmers L. Weaver, *Annals of Mathematical Statistics*, June, 1946.

FIG. 13.41 OPERATING CHARACTERISTICS OF THE ONE-SIDED F TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.05.

FIG. 13.42 OPERATING CHARACTERISTICS OF THE ONE-SIDED F TEST FOR A LEVEL OF SIGNIFICANCE EQUAL TO 0.01.

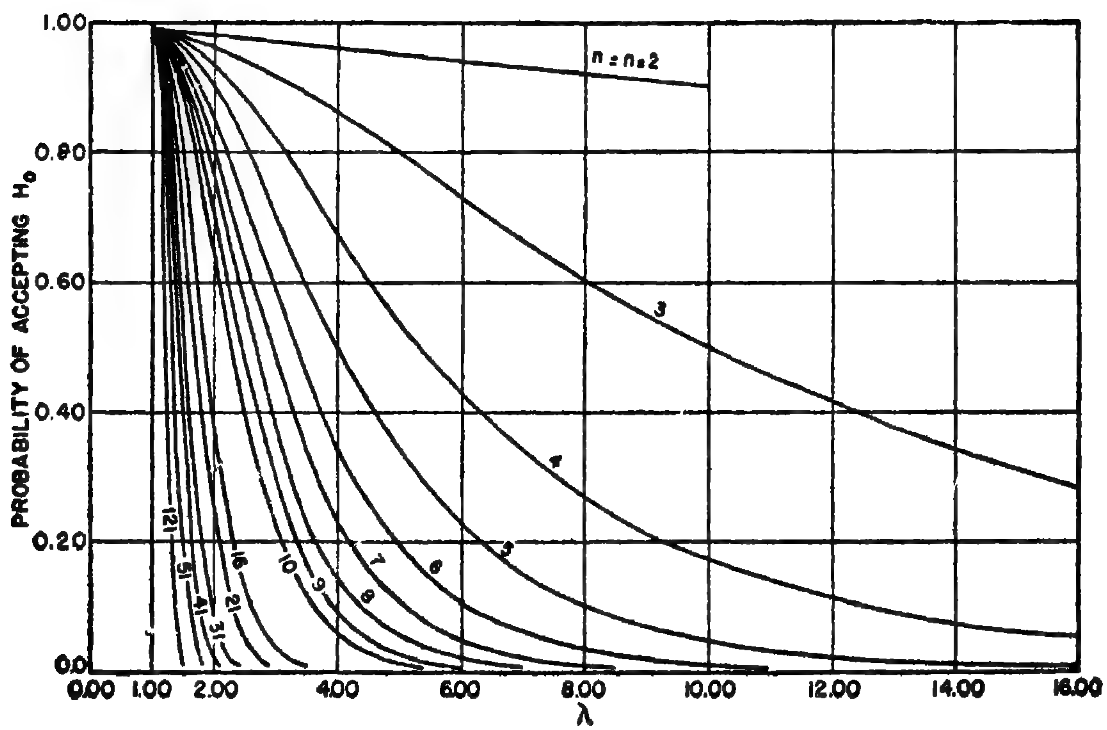


TABLE **13.28** SUMMARY OF ESTIMATES BY CONFIDENCE INTERVALS AND BY SINGLE POINTS

Parameters	Notation	Qualifying conditions	Formula	Tables to find percentage points	Point estimates
Mean of a normal distribution	μ	known σ	$\bar{x} - K_{\alpha/2}(\sigma/\sqrt{n}) \leq \mu \leq \bar{x} + K_{\alpha/2}(\sigma/\sqrt{n})$	Normal table, Table 13.3	$\bar{x}$
Standard deviation of a normal distribution	σ		$s\sqrt{\dfrac{n-1}{\chi^2_{\alpha/2;n-1}}} \leq \sigma \leq s\sqrt{\dfrac{n-1}{\chi^2_{1-\alpha/2;n-1}}}$	Chi-square table, Table 13.26	s
Mean of a normal distribution	μ	unknown σ	$\bar{x} - (t_{\alpha/2;n-1})\dfrac{s}{\sqrt{n}} \leq \mu \leq \bar{x} + (t_{\alpha/2;n-1})\dfrac{s}{\sqrt{n}}$	t tables, Table 13.25	$\bar{x}$
Difference between the means of two normal distributions	$\Delta = \mu_x - \mu_y$	$x_1, \ldots, x_{n_x}$ are observations in first sample; $y_1, \ldots, y_{n_y}$ are observations in second sample.	$\bar{x} - \bar{y} - K_{\alpha/2}\sqrt{\left(\dfrac{\sigma_x^2}{n_x} + \dfrac{\sigma_y^2}{n_y}\right)} \leq \Delta \leq \bar{x} - \bar{y} + K_{\alpha/2}\sqrt{\left(\dfrac{\sigma_x^2}{n_x} + \dfrac{\sigma_y^2}{n_y}\right)}$		$\bar{x} - \bar{y}$
Difference between the means of two normal distributions	$\Delta = \mu_x - \mu_y$	$\sigma_x = \sigma_y = \sigma$ unknown σ	$(\bar{x} - \bar{y}) - t_{\alpha/2;n_x+n_y-2}\sqrt{\dfrac{1}{n_x} + \dfrac{1}{n_y}}\sqrt{\dfrac{\sum(x_i - \bar{x})^2 + \sum(y_i - \bar{y})^2}{n_x + n_y - 2}}$ $\leq \Delta \leq (\bar{x} - \bar{y}) + [t_{\alpha/2;n_x+n_y-2}]$ $\left[\sqrt{\dfrac{1}{n_x} + \dfrac{1}{n_y}}\sqrt{\dfrac{\sum(x_i - \bar{x})^2 + \sum(y_i - \bar{y})^2}{n_x + n_y - 2}}\right]$		$\bar{x} - \bar{y}$

be to present the average of these numbers as an estimate of the mean breaking strength, and this is the best estimate if a single number is desired. However, this single number may by chance depart substantially from the true mean value, and no indication of the magnitude of the departure is available. For many purposes, a more useful estimate is an interval which contains the true value with high probability.

Procedures for calculating confidence intervals most likely to arise in practical work are given in Table 13.28; these intervals usually involve percentage points of the standard distributions that are presented in Tables 13.3, 13.25, and 13.26. The notation for the percentage points is explained in Table 13.28.

5. CURVE FITTING

5.1 INTRODUCTION

It is common practice for engineers to represent relationships by means of graphs. Although these graphs are depicted as smooth curves, rarely do the experimental points lie on the fitted curves. This is usually explained by the fact that the experimental points are chance variables. The usual procedures are to plot the points and (1) connect all the points as in Fig. 13.43; (2) fair the best line in by eye as in Fig. 13.44; (3) fair the best curve in by eye as in Fig. 13.45.

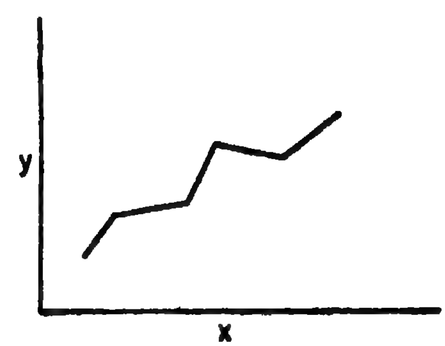


FIG. 13.43 RELATION BETWEEN x AND y OBTAINED BY CONNECTING POINTS.

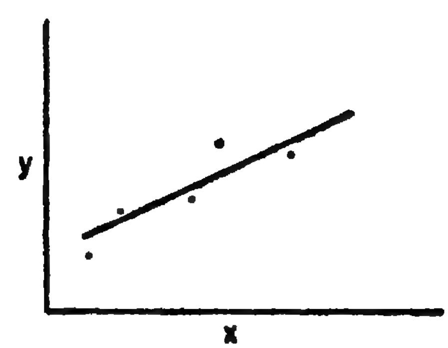


FIG. 13.44 RELATION BETWEEN x AND y OBTAINED BY DRAWING IN BEST LINE BY EYE.

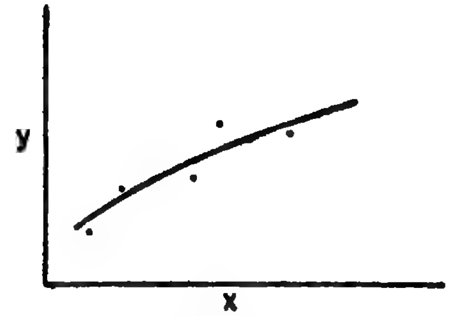


FIG. 13.45 RELATION BETWEEN x AND y OBTAINED BY DRAWING IN BEST CURVE BY EYE.

It is useful to discuss these three methods when there is a priori knowledge that the plotted relation is linear and when the plotted relation is curvilinear.

If there is an underlying linear relationship, procedure (1) has serious implications. In the first place, the problem is really to obtain the best estimate of the true underlying relationship (the word estimate is used because on the basis of a sample the true relationship is never obtained). The procedure pictured in Fig. 13.43 does not represent a linear relationship, and it is intuitively evident that the best estimate of a straight line should be a straight line. Furthermore, the performance of another experiment with the same variables would lead to a completely different graph. Very little confidence can be placed in curves that will differ radically with the performance of another experiment using the same variables. Frequently, graphs are used for prediction purposes, and no statements about the chances of being right or wrong can be made if procedure (1) is used.

The second procedure depicted in Fig. 13.44 is probably most commonly used. This has two serious disadvantages. Two people confronted with the same data will draw different lines through the points, so that there is not a single interpretation of the data. If these graphs are used for prediction purposes, the best point estimates based on the faired line will differ for different people. Furthermore, since fairing in a line is not an objective procedure, probability statements about the slope and intercept cannot be made.

The third procedure depicted in Fig. 13.45 can be dismissed for essentially the same reasons as those for procedures (1) and (2). In addition, it is again intuitively evident that the best estimate of a true linear relationship should be a straight line.

If the underlying relationship is curvilinear, the three procedures can be dismissed for essentially the same reasons as discussed above.

The method commonly used for fitting linear and curvilinear relations is the method of least squares. Besides the advantage of giving a unique solution, i.e., a single line, this procedure has several optimum statistical properties. Furthermore, with some knowledge about the underlying distribution, confidence statements about the parameters can be made.

5.2 SIMPLE LINEAR CURVE FITTING

Two cases will be distinguished, namely, where there exists an underlying physical linear relationship, and where there exists a degree of association between the variables.

5.2.1 An underlying physical linear relationship. In this case, there is a mathematical relationship of the form $y = B_0 + B_1x$, which relates the variables. Examples of this case are the equations of physics:

$$\text{velocity} = \text{acceleration} \times \text{time} + \text{initial velocity}$$

$$\text{force} = \text{mass} \times \text{acceleration}$$

where the intercept, in the second example, is 0. Upon accumulating data for such relations, all the observed points $y_1, y_2, \ldots, y_n$ do not lie on a straight line because of experimental errors. However, it is reasonable to assume that the distribution of errors is such that for a fixed value of x, the population mean value of the y's is $B_0 + B_1x$, where B_0 and B_1 are the intercept and slope to be estimated from a sample $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$. Here x is the independent variable and is *assumed* to be known without error. From a practical point of view, it is sufficient to have the error in x small compared with the variability in y. In this section it will be assumed that $y_1, y_2, \ldots, y_n$ are independent chance variables having a normal distribution* with mean $B_0 + B_1x$ and standard deviation σ (constant for all x_i).

5.2.2 A degree of association between chance variables x and y. Measurements on one variable, say x, may be relatively inexpensive compared with measurements on y. Consequently, one would like to predict y from a knowledge of x. For example, determining abrasion loss is difficult, whereas measuring hardness by means of a Rockwell hardness machine is relatively simple. There exists a degree of association between abrasion loss and hardness. Similarly, rainfall in one area is associated with rainfall in a surrounding area. From measurements of the amount of rainfall in one area, one would like to predict rainfall in the other area.

A linear relationship exists between x and y if for a fixed x, the population mean value of y, given x, is of the form $B_0 + B_1x$. A sufficient condition for the existence of a linear relationship is that both x and y have a bivariate normal distribution.† The model implies that the actual observations $y_1, y_2, \ldots, y_n$ should not be on a straight line, but for fixed x, the population mean value of y should fall on the line $B_0 + B_1x$, where B_0 and B_1 are the intercept and slope, respectively, to be estimated from a sample $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$. In this section it will be assumed that the y's are at least independ-

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* The equations for the least square estimates of B_0 and B_1 do not depend on the assumption of normality. However, tests of hypothesis and confidence statements presented later do depend on this assumption.

† If x and y are related such that x is normally distributed, the mean of y, given x, is a linear function of x, and the variance of y, given x, is constant, x and y are said to have a bivariate normal distribution.

ently normally distributed* with mean $B_0 + B_1x$ and standard deviation σ (for all x_i).†

Thus, returning to the abrasion loss-hardness example, if it is assumed that abrasion loss y and hardness x have a bivariate normal distribution, the average value of abrasion loss, given hardness, is $B_0 + B_1$ (hardness).

5.3 LEAST SQUARE ESTIMATES OF B_0 AND B_1

It should be noted that the cases presented in Arts. 5.2.1 and 5.2.2 fall into the general model of the following:

For fixed x, the $y_1, y_2, \ldots, y_n$ are independently normally distributed with mean value $B_0 + B_1x$ and standard deviation σ (for all x_i).

The problem is to estimate B_0 and B_1 by the method of least squares. Denote by b_0 and b_1 the least squares estimates of B_0 and B_1, respectively. The line is of the form $\tilde{y} = b_0 + b_1x$ and is usually referred to in statistics as a regression line. The least squares estimates of B_0 and B_1 are obtained by minimizing the sum of squares of the deviations about the estimated line with respect to b_0 and b_1, i.e., minimizing $\sum_{i=1}^{n} (y_i - \tilde{y}_i)^2$. The results are

$$b_1 = \frac{\sum_{i=1}^{n} (y_i - \bar{y})(x_i - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} = \frac{\sum_{i=1}^{n} x_iy_i - n\bar{x}\bar{y}}{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2}$$

$$b_0 = \bar{y} - b_1\bar{x}$$

5.4 SIGNIFICANCE TEST FOR B_0 AND B_1

In Art. 4 various significance tests for the mean and standard deviation of a normal distribution are given. In a similar manner, significance tests can be made for B_0 and B_1, and these are outlined in Table 13.29. These tests depend on the assumptions mentioned above. The reader is referred to the discussion in Art. 4 regarding significance tests.

5.5 POINT ESTIMATES AND CONFIDENCE INTERVALS FOR THE LINEAR MODEL

The point estimates and interval estimates for the various parameters are given in Table 13.30.

5.6 PREDICTING AN INTERVAL WITHIN WHICH A FUTURE OBSERVATION y^* CORRESPONDING TO x^* WILL LIE

Table 13.30 presents a confidence interval for the parameter, the mean value of y^* corresponding to x^*. It is often the case that a confi-

* The equations for the least square estimates of B_0 and B_1 do not depend on the assumption of normality. However, tests of hypothesis and confidence statements presented later do depend on this assumption.

† That x and y have a bivariate normal distribution implies this condition.

TABLE 13.29 SIGNIFICANCE TESTS FOR COEFFICIENTS OF STRAIGHT LINE

Hypothesis	Test statistic[a]	Rule of rejection[b]
$B_0 = B'_0$	$t = \dfrac{b_0 - B'_0}{\sqrt{s^2_{y\|x}\left(\dfrac{1}{n} + \dfrac{\bar{x}^2}{\sum (x_i - \bar{x})^2}\right)}}$	$\|t\| \geq t_{\alpha/2;n-2}$
$B_1 = B'_1$	$t = \dfrac{b_1 - B'_1}{\sqrt{s^2_{y\|x}\,(1/\sum (x_i - \bar{x})^2)}}$	$\|t\| \geq t_{\alpha/2;n-2}$
$B_0^{xy} = B_0^{uv}$ where mean $y = B_0^{xy} + B_1^{xy}x$; mean $v = B_0^{uv} + B_1^{uv}u$	$t = \dfrac{b_0^{xy} - b_0^{uv}}{\sqrt{\dfrac{(n_{xy}-2)s^2_{y\|x} + (n_{uv}-2)s^2_{v\|u}}{n_{xy}+n_{uv}-4}}\sqrt{\dfrac{1}{n_{xy}} + \dfrac{1}{n_{uv}} + \dfrac{\bar{x}^2}{\sum (x_i - \bar{x})^2} + \dfrac{\bar{u}^2}{\sum (u_i - \bar{u})^2}}}$	$\|t\| \geq t_{\alpha/2;n_{xy}+n_{uv}-4}$
$B_1^{xy} = B_1^{uv}$ where mean $y = B_0^{xy} + B_1^{xy}x$; mean $v = B_0^{uv} + B_1^{uv}u$	$t = \dfrac{b_1^{xy} - b_1^{uv}}{\sqrt{\dfrac{(n_{xy}-2)s^2_{y\|x} + (n_{uv}-2)s^2_{v\|u}}{n_{xy}+n_{uv}-4}}\sqrt{\dfrac{1}{\sum (x_i - \bar{x})^2} + \dfrac{1}{\sum (u_i - \bar{u})^2}}}$	$\|t\| \geq t_{\alpha/2;n_{xy}+n_{uv}-4}$

TABLE 13.29 SIGNIFICANCE TESTS FOR COEFFICIENTS OF STRAIGHT LINE (*Continued*)

OC curve	Notation
Compute $d = \dfrac{\lvert B'_0 - B^*_0\rvert}{\sigma\sqrt{[1/n + \bar{x}^2/\sum (x_i - \bar{x})^2]\,(n-1)}}$ and refer to Fig. 13.29 or 13.30, using the curve for $n - 1$.	Here σ is the standard deviation of y about the mean $B_0 + B_1x$, $s^2_{y\mid x}$ is the estimate of σ^2, and is equal to $s^2_{y\mid x} = \dfrac{\sum_{i=1}^{n} [y_i - (b_0 + b_1x_i)]^2}{n-2} = \dfrac{\sum (y_i - \bar{y})^2 - \dfrac{[\sum (x_i - \bar{x})(y_i - \bar{y})]^2}{\sum (x_i - \bar{x})^2}}{n-2}$ where B_0^* is the value of the true intercept for use in referring to the OC curve.
Compute $d = \dfrac{\lvert B'_1 - B^*_1\rvert}{\sigma\sqrt{(n-1)/\sum (x_i - \bar{x})^2}}$ and refer to Fig. 13.29 or 13.30, using the curve for $n - 1$.	Here B^*_1 is the value of the true slope for use in referring to the OC curve.
Compute $d = \dfrac{\lvert\delta_0\rvert}{\sqrt{n_{xy} + n_{uv} - 3}\;\sigma_{y\mid x}\sqrt{\dfrac{1}{n_{xy}} + \dfrac{1}{n_{uv}} + \dfrac{\bar{x}^2}{\sum (x_i - \bar{x})^2} + \dfrac{\bar{u}^2}{\sum (u_i - \bar{u})^2}}}$ and refer to Fig. 13.29 or 13.30, using the curve for $n_{xy} + n_{uv} - 3$.	This is the problem of comparing coefficients from two straight lines. The subscripts x and y refer to one line, whereas u and v refer to the second line. Then $\sigma_{y\mid x}$ is the unknown standard deviation of y about the mean $B_0^{xy} + B_1^{xy}x$, and $\sigma_{v\mid u}$ is the unknown standard deviation of v about the mean $B_0^{uv} + B_1^{uv}u$. It is assumed that $\sigma_{y\mid x} = \sigma_{v\mid u}$; δ_0 is the difference in intercept of the two lines for use in referring to the OC curve. Here δ_1 is the difference in slopes of the two lines for use in referring to the OC curve.
Compute $d = \dfrac{\lvert\delta_1\rvert}{\sigma_{y\mid x}\sqrt{\left(\dfrac{1}{\sum (x_i - \bar{x})^2} + \dfrac{1}{\sum (u_i - \bar{u})^2}\right)(n_{xy} + n_{uv} - 3)}}$ and refer to Fig. 13.29 or 13.30, using the curve for $n_{xy} + n_{uv} - 3$.	

[a] If the population standard deviation is known, these values should be used in place of the sample estimates, and K_α should be used instead of t_α.
[b] These values are for two-sided tests, and the values of t_α are given in Table 13.25.

TABLE 13.30 ESTIMATION OF PARAMETERS FOR LINEAR MODEL

Parameter	Symbol for estimate	Estimation computation formula	$100(1-\alpha)\%$ confidence interval	Notes
B_1	b_1	$\dfrac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2}$	$b_1 \pm \dfrac{t_{(\alpha/2;n-2)}\, s_{y\mid x}}{\sqrt{\sum (x_i - \bar{x})^2}}$	
B_0	b_0	$\bar{y} - b_1\bar{x}$	$b_0 \pm t_{(\alpha/2;n-2)}\, s_{y\mid x}\sqrt{\dfrac{1}{n} + \dfrac{\bar{x}^2}{\sum (x_i - \bar{x})^2}}$	
Average value of y corresponding to x^*, i.e., $B_0 + B_1x^*$	$\bar{y}^*$	$b_0 + b_1x^*$	$b_0 + b_1x^* \pm t_{(\alpha/2;n-2)}\, s_{y\mid x}\sqrt{\dfrac{1}{n} + \dfrac{(x^* - \bar{x})^2}{\sum (x_i - \bar{x})^2}}$	
Value of x corresponding to observed value of y' for the case when there is an underlying physical relationship.	x'	$\dfrac{y' - b_0}{b_1} = x'$	$x' + b_1\dfrac{(y' - \bar{y})}{c}$ $\pm\, t_{(\alpha/2;n-2)}\dfrac{s_{y\mid x}}{c}\sqrt{\left(1 + \dfrac{1}{n}\right)c + A(y' - \bar{y})^2}$	$c = b_1^2 - t^2_{\alpha/2}(s^2_{y\mid x})(A)$ $A = 1/\sum (x_i - \bar{x})^2$ If $(x' - \bar{x})^2/\sum (x_i - \bar{x})^2$ is small, then we have for the confidence interval, $(y' - b_0)/b_1 \pm t_{\alpha/2}\, s_{y\mid x}\sqrt{(1 + 1/n)}/b_1$
$\sigma^2_{y\mid x}$	$s^2_{y\mid x}$	$\dfrac{\sum [y_i - (b_0 + b_1x_i)]^2}{n-2} = \dfrac{\sum (y_i - \bar{y})^2 - [\sum (x_i - \bar{x})(y_i - \bar{y})]^2/\sum (x_i - \bar{x})^2}{n-2}$	$\dfrac{(n-2)s^2_{y\mid x}}{\chi^2_{\alpha/2;n-2}};\ \dfrac{(n-2)s^2_{y\mid x}}{\chi^2_{1-\alpha/2;n-2}}$	

dence statement about the mean value is unimportant, whereas a probability statement about a future observation is relevant. For example, tensile strength of cement is related to the curing time (t) by: strength $= \alpha e^{-\beta/t}$. This function is transformed by taking logarithms:

$$\ln \text{strength} = \ln \alpha - \frac{\beta}{t} = \ln \alpha - \beta z$$

where $z = 1/t$, which is now linear in z and can be estimated by the method of least squares. The cement manufacturer is interested in the average tensile strength of his cement after a particular period of time, i.e., a confidence statement, whereas a builder is interested in the tensile strength of his particular batch of cement to determine whether it will carry the required load. After a specified period of time, say 28 days, the builder would like to have such a statement as the probability is $1 - \alpha$ that the tensile strength of his batch of cement will lie in a specified interval.

The following statement can be made. The probability is $1 - \alpha$ that the value of a future observation y^* corresponding to x^* will lie in the interval

$$b_0 + b_1 x^* \pm t_{(\alpha/2; n-2)}\, s_{y|x} \sqrt{1 + \frac{1}{n} + \frac{(x^* - \bar{x})^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2}}$$

5.7 CORRELATION

A measure of the degree of association between two variables is the correlation coefficient ρ. An estimate of ρ is given by the sample correlation coefficient r, which is defined

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

In engineering applications, the correlation coefficient does not play a very important role. The correlation coefficient can be derived from the slope of the fitted least squares line, e.g.,

$$r = b_1 \sqrt{\frac{\sum (x_i - \bar{x})^2}{\sum (y_i - \bar{y})^2}}$$

Consequently it is clear that the correlation coefficient does not contain any additional information. However, a significance test for $\rho = 0$ is equivalent to testing whether $B_1 = 0$, i.e., whether or not a linear relation is present. The test for $B_1 = 0$ is given in Table 13.29.

To test the hypothesis that $\rho = 0$, reject when

$$|t| = \left| \frac{r}{\sqrt{1 - r^2}} \right| \sqrt{n - 2} \geq t_{\alpha/2}$$

where values of t_α can be found in Table 13.25.

TABLE 13.31 WORKSHEET FOR THE FITTING OF STRAIGHT LINES BY THE METHOD OF LEAST SQUARES

General data	Data for confidence intervals and predictions for $x = x^*$
x represents ———	Data for the equation of line
$\sum_{i=1}^{n} x_i =$ ——; $\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} =$ ——; $\left(\sum_{i=1}^{n} x_i\right)^2 / n = \left(\sum_{i=1}^{n} x_i\right)(\bar{x}) =$ ——	$b_1 = \dfrac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} =$ ——
$\sum_{i=1}^{n} x_i^2 =$ ——; $\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2 / n = \sum_{i=1}^{n} (x_i - \bar{x})^2 =$ ——	
y represents ———	$b_0 = \bar{y} - b_1\bar{x} =$ ——
$\sum_{i=1}^{n} y_i =$ ——; $\bar{y} = \sum_{i=1}^{n} \frac{y_i}{n} =$ ——; $\left(\sum_{i=1}^{n} y_i\right)^2 / n = \left(\sum_{i=1}^{n} y_i\right)(\bar{y}) =$ ——	equation of line $= \hat{y} = b_0 + b_1 x$ $=$ —— $+$ —— x
$\sum_{i=1}^{n} y_i^2 =$ ——; $\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2 / n = \sum_{i=1}^{n} (y_i - \bar{y})^2 =$ ——	Estimate of standard deviation
$n =$ ——; $\frac{1}{n} =$ ——; $\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)/n = (\bar{x}) \sum_{i=1}^{n} y_i =$ ——	$(n-2)(s^2_{y\mid x}) = \sum_{i=1}^{n} (y_i - \bar{y})^2$
$\sum_{i=1}^{n} x_i y_i =$ ——; $\sum_{i=1}^{n} x_i y_i - (\sum x_i)(\sum y_i)/n = \sum (x_i - \bar{x})(y_i - \bar{y}) =$ ——	$- \dfrac{\left[\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})\right]^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2} =$ ——
$\dfrac{\left[\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})\right]^2}{\sum (x_i - \bar{x})^2} =$ ——	$s^2_{y\mid x} =$ ——; $s_{y\mid x} = \sqrt{s^2_{y\mid x}} =$ ——

TABLE 13.31 WORKSHEET FOR THE FITTING OF STRAIGHT LINES BY THE METHOD OF LEAST SQUARES (*Continued*)

Data for significance tests	Data for confidence intervals and predictions for $x = x^*$
$\dfrac{s^2_{y\mid x}}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = \underline{\qquad}$; $\sqrt{\dfrac{s^2_{y\mid x}}{\sum_{i=1}^{n}(x_i - \bar{x})^2}} = \underline{\qquad}$; $\bar{x}^2 = \underline{\qquad}$	$(x^* - \bar{x})^2 = \underline{\qquad}$; $\dfrac{(x^* - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = \underline{\qquad}$
$\dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = \underline{\qquad}$; $\dfrac{1}{n} + \dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = \underline{\qquad}$	$\dfrac{1}{n} + \dfrac{(x^* - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = \underline{\qquad}$
$(s^2_{y\mid x})\left[\dfrac{1}{n} + \dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}\right] = \underline{\qquad}$	$(s^2_{y\mid x})\left[\dfrac{1}{n} + \dfrac{(x^* - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}\right] = \underline{\qquad}$
$\sqrt{(s^2_{y\mid x})\left[\dfrac{1}{n} + \dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}\right]} = \underline{\qquad}$	$\sqrt{(s^2_{y\mid x})\left[\dfrac{1}{n} + \dfrac{(x^* - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}\right]} = \underline{\qquad}$
	$1 + \dfrac{1}{n} + \dfrac{(x^* - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = \underline{\qquad}$
	$(s^2_{y\mid x})\left[1 + \dfrac{1}{n} + \dfrac{(x^* - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}\right] = \underline{\qquad}$
	$\sqrt{(s^2_{y\mid x})\left[1 + \dfrac{1}{n} + \dfrac{(x^* - \bar{x})^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}\right]} = \underline{\qquad}$

TABLE 13.31a WORKSHEET FOR THE FITTING OF STRAIGHT LINES BY THE METHOD OF LEAST SQUARES

General data

x represents nominal value

$$\sum_{i=1}^{n} x_i = 27.0; \quad \bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} = 1.125; \quad \left(\sum_{i=1}^{n} x_i\right)^2 \Big/ n = \left(\sum_{i=1}^{n} x_i\right)(\bar{x}) = 30.375$$

$$\sum_{i=1}^{n} x_i^2 = 38.2500; \quad \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2 \Big/ n = \sum_{i=1}^{n} (x_i - \bar{x})^2 = 7.875$$

y represents actual value

$$\sum_{i=1}^{n} y_i = 27.022; \quad \bar{y} = \sum_{i=1}^{n} \frac{y_i}{n} = 1.1259; \quad \left(\sum_{i=1}^{n} y_i\right)^2 \Big/ n = \left(\sum_{i=1}^{n} y_i\right)(\bar{y}) = 30.424552$$

$$\sum_{i=1}^{n} y_i^2 = 38.279818; \quad \sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2 \Big/ n = \sum_{i=1}^{n} (y_i - \bar{y})^2 = 7.855266$$

$$n = 24; \quad \frac{1}{n} = 0.041667; \quad \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right) \Big/ n = (\bar{x}) \sum_{i=1}^{n} y_i = 30.39975$$

$$\sum_{i=1}^{n} x_i y_i = 38.26375; \quad \sum_{i=1}^{n} x_i y_i - \left(\sum x_i\right)\left(\sum y_i\right)/n = \sum (x_i - \bar{x})(y_i - \bar{y}) = 7.86400$$

$$\frac{\left[\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})\right]^2}{\sum (x_i - \bar{x})^2} = \underline{\qquad}$$

Data for confidence intervals and predictions for $x = x^*$

Data for the equation of line

$$b_1 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} = 0.998603$$

$$b_0 = \bar{y} - b_1 \bar{x} = -0.000672882$$

$$\text{equation of line} = \hat{y} = b_0 + b_1 x$$
$$= 0.000672882 + 0.998603x$$

Estimate of standard deviation

$$(n - 2)(s^2_{y|x}) = \sum_{i=1}^{n} (y_i - \bar{y})^2 - \frac{\left(\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})\right)^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2} = 0.0023$$

$$s^2_{y|x} = 0.00010455; \quad s_{y|x} = \sqrt{s^2_{y|x}} = 0.010225$$

TABLE 13.31a WORKSHEET FOR THE FITTING OF STRAIGHT LINES BY THE METHOD OF LEAST SQUARES (*Continued*)

Data for significance tests	Data for confidence intervals and predictions for $x = x^*$
$\dfrac{s^2_{y\mid x}}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = \_\_\_\_;\quad \sqrt{\dfrac{s^2_{y\mid x}}{\sum_{i=1}^{n}(x_i-\bar{x})^2}} = \_\_\_\_;\quad \bar{x}^2 = \_\_\_\_$	$(x^*-\bar{x})^2 = 0.015625;\quad \dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = 0.001984$
$\dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = \_\_\_\_;\quad \dfrac{1}{n} + \dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = \_\_\_\_$	$\dfrac{1}{n} + \dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = 0.043651$
$(s^2_{y\mid x})\left[\dfrac{1}{n} + \dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right] = \_\_\_\_$	$(s^2_{y\mid x})\left[\dfrac{1}{n} + \dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right] = 0.000004564$
$\sqrt{(s^2_{y\mid x})\left[\dfrac{1}{n} + \dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right]} = \_\_\_\_$	$\sqrt{(s^2_{y\mid x})\left[\dfrac{1}{n} + \dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right]} = 0.002136$
	$1 + \dfrac{1}{n} + \dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = 1.043651$
	$(s^2_{y\mid x})\left[1 + \dfrac{1}{n} + \dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right] = 0.0001091$
	$\sqrt{(s^2_{y\mid x})\left[1 + \dfrac{1}{n} + \dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right]} = 0.01045$

5.7.1 Example. A screw manufacturer is interested in giving out data to his customers on the relation between nominal and actual lengths. The following results were observed:

Nominal x	Actual y		
$\frac{1}{4}$ in.	0.262	0.262	0.245
$\frac{1}{2}$	0.496	0.512	0.490
$\frac{3}{4}$	0.743	0.744	0.751
1	0.976	1.010	1.004
$1\frac{1}{4}$	1.265	1.254	1.252
$1\frac{1}{2}$	1.498	1.518	1.504
$1\frac{3}{4}$	1.738	1.759	1.750
2	2.005	1.992	1.992

In this problem, there is a definite physical relation

$$\text{actual value} = B_0 + B_1 \text{ (nominal value)}$$

If the manufacturing process were perfect, it would be expected that $B_0 = 0$ and $B_1 = 1$. It should be noted that without using regression, one could make a confidence statement about the average of length of "1-inch" screws on the basis of the three numbers in the table; but a much more precise statement can be made by using all the data, together with the fact that linear regression is applicable. (1) Estimate the above relation. (2) For nominal 1-in. screws, find a confidence interval for the average actual value of screw length. (3) For a 1-in. screw find an interval such that the actual value will lie in this interval with probability 0.95.

(1) Estimated line: $\tilde{y} = 0.000672882 + 0.998603x$

(2) Confidence interval for the average actual value of 1-in. screws:

$$b_0 + b_1x^* \pm t_{(\alpha/2;n-2)}\, s_{y|x}\sqrt{\frac{1}{n} + \frac{(x^* - \bar{x})^2}{\sum (x_i - \bar{x})^2}}$$

$$0.000672882 + 0.998603 \pm 2.074 \times 0.002136$$

$$0.99485 \leq \text{average actual value} \leq 1.00371$$

(3) Interval such that the probability is 0.95 that the true length of a 1-in. screw will be in this interval:

$$0.999275 \pm 0.01045 \times 2.074$$

$$0.97760 \leq \text{true length} \leq 1.02095$$

5.7.2 Example. The following results on the tensile strength of specimens of cold drawn copper have been recorded in a laboratory.

These variables fall into the second category, namely, a degree of association between x and y. Furthermore, it is reasonable to assume that x and y have a bivariate normal distribution, so that the population mean value of $y = B_0 + B_1x$. Hence, it remains to find the estimated line $\tilde{y} = b_0 + b_1x$ by the method of least squares. (1) Test the hypothesis that $B_0 = -100{,}000$. (2) Test the hypothesis that $B_1 = 1900$. (3) Get 95% confidence intervals for B_1; B_0; the mean value of tensile strength corresponding to a Brinell hardness of 105.0; and $\sigma_{y|x}$. (4) Find an interval such that the probability is 0.95 that the value of tensile strength for a Brinell hardness of 105.0 will lie in this interval.

y Tensile strength (psi)	x Brinell hardness number
38,871	104.2
40,407	106.1
39,887	105.6
40,821	106.3
33,701	101.7
39,481	104.4
33,003	102.0
36,999	103.8
37,632	104.0
33,213	101.5
33,911	101.9
29,861	100.6
39,451	104.9
40,647	106.2
35,131	103.1

(1) Hypothesis: $B_0 = -100{,}000$; reject if

$$|t| = \left|\frac{b_0 + 100{,}000}{\sqrt{s^2_{y|x}[1/n + \bar{x}^2/\sum (x_i - \bar{x})^2]}}\right| \geq t_{.025,13} = 2.160$$

$$|t| = \left|\frac{-149{,}786.5 + 100{,}000}{11{,}879.8}\right| = 4.19 \geq 2.160$$

Therefore reject the hypothesis that $B_0 = -100{,}000$.

(2) Hypothesis: $B_1 = 1900$; reject if

$$|t| = \left|\frac{b_1 - 1900}{\sqrt{s^2_{y|x}(1/\sum (x_i - \bar{x})^2)}}\right| \geq t_{.025,13} = 2.160$$

$$|t| = \left|\frac{1799.025 - 1900}{114.5}\right| = 0.881 < 2.160$$

Therefore accept the hypothesis that $B_1 = 1900$.

(3) Confidence intervals:

(a) for B_1

$$b_1 \pm \frac{t_{\alpha/2;n-2}\, s_{y|x}}{\sqrt{\sum (x_i - \bar{x})^2}}$$

$$1799.025 \pm 2.160(114.5)$$

$$1551.7 \leq B_1 \leq 2046.3$$

(b) for B_0

$$b_0 \pm t_{\alpha/2;n-2}\, s_{y|x}\sqrt{\frac{1}{n} + \frac{\bar{x}^2}{\sum (x_i - \bar{x})^2}}$$

$$-149{,}786.5 \pm 2.160(11{,}879.8)$$

$$-175{,}446.9 \leq B_0 \leq -124{,}126.1$$

(c) for mean value of tensile strength corresponding to a Brinell hardness of 105.0.

$$b_0 + b_1 x^* \pm t_{\alpha/2;n-2}\, s_{y|x}\sqrt{\frac{1}{n} + \frac{(x^* - \bar{x})^2}{\sum (x_i - \bar{x})^2}}$$

$$-149{,}786.5 + 1{,}799.025(105.0) \pm 2.160(252.56) = 39{,}111.1 \pm 545.53$$

$$38{,}565.6 \leq \text{mean value of tensile strength} \leq 39{,}656.6$$

TABLE 13.31b WORKSHEET FOR THE FITTING OF STRAIGHT LINES BY THE METHOD OF LEAST SQUARES

General data

x represents Brinell hardness number

$$\sum_{i=1}^{n} x_i = 1556.3; \quad \bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} = 103.753; \quad \left(\sum_{i=1}^{n} x_i\right)^2 \Big/ n = \left(\sum_{i=1}^{n} x_i\right)(\bar{x}) = 161{,}471.3126$$

$$\sum_{i=1}^{n} x_i^2 = 161{,}520.87; \quad \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2 \Big/ n = \sum_{i=1}^{n} (x_i - \bar{x})^2 = 49.56$$

y represents tensile strength

$$\sum_{i=1}^{n} y_i = 553{,}016; \quad \bar{y} = \sum_{i=1}^{n} \frac{y_i}{n} = 36{,}867.7; \quad \left(\sum_{i=1}^{n} y_i\right)^2 \Big/ n = \left(\sum_{i=1}^{n} y_i\right)(\bar{y}) = 20{,}388{,}446{,}420$$

$$\sum_{i=1}^{n} y_i^2 = 20{,}557{,}291{,}078; \quad \sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2 \Big/ n = \sum_{i=1}^{n} (y_i - \bar{y})^2 = 168{,}844{,}660$$

$$n = 15; \quad \frac{1}{n} = 0.0666667; \quad \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right) \Big/ n = (\bar{x}) \sum_{i=1}^{n} y_i = 57{,}377{,}253.38$$

$$\sum_{i=1}^{n} x_i y_i = 57{,}466{,}413.1; \quad \sum_{i=1}^{n} x_i y_i - \left(\sum x_i\right)\left(\sum y_i\right)/n = \sum (x_i - \bar{x})(y_i - \bar{y}) = 89{,}159.7$$

$$\frac{\left[\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})\right]^2}{\sum (x_i - \bar{x})^2} = 160{,}400{,}567$$

Data for confidence intervals and predictions for $x = x^*$

Data for the equation of line

$$b_1 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} = 1{,}799.025$$

$$b_0 = \bar{y} - b_1\bar{x} = -149{,}786.5$$

equation of line is $\hat{y} = b_0 + b_1 x$

$$= -149{,}786.5 + 1{,}799.025x$$

Estimate of standard deviation

$$(n-2)(s^2_{y|x}) = \sum_{i=1}^{n} (y_i - \bar{y})^2 - \frac{\left[\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})\right]^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2} = 8{,}444{,}093$$

$$s^2_{y|x} = 649{,}546; \quad s_{y|x} = \sqrt{s^2_{y|x}} = 805.945$$

TABLE **13.31b** WORKSHEET FOR THE FITTING OF STRAIGHT LINES BY THE METHOD OF LEAST SQUARES (*Continued*)

Data for significance tests	Data for confidence intervals and predictions for $x = x^*$
$\dfrac{s^2_{y\|x}}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = 13{,}106$; $\sqrt{\dfrac{s^2_{y\|x}}{\sum_{i=1}^{n}(x_i-\bar{x})^2}} = 114.5$; $\bar{x}^2 = 10{,}764.7$	$(x^*-\bar{x})^2 = 1.555$; $\dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = 0.03135$
$\dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = 217.2051$; $\dfrac{1}{n}+\dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = 217.2718$	$\dfrac{1}{n}+\dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = 0.0982$
$(s^2_{y\|x})\left[\dfrac{1}{n}+\dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right] = 141{,}128{,}029$	$(s^2_{y\|x})\left[\dfrac{1}{n}+\dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right] = 63{,}785.4$
$\sqrt{(s^2_{y\|x})\left[\dfrac{1}{n}+\dfrac{\bar{x}^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right]} = 11{,}879.8$	$\sqrt{(s^2_{y\|x})\left[\dfrac{1}{n}+\dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right]} = 252.56$
	$1+\dfrac{1}{n}+\dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2} = 1.0982$
	$(s^2_{y\|x})\left[1+\dfrac{1}{n}+\dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right] = 713{,}331.4$
	$\sqrt{(s^2_{y\|x})\left[1+\dfrac{1}{n}+\dfrac{(x^*-\bar{x})^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\right]} = 844.59$

(d) for $\sigma^2_{y|x}$

$$\frac{(n-2)s^2_{y|x}}{\chi^2_{(\alpha/2;n-2)}};\qquad \frac{(n-2)s^2_{y|x}}{\chi^2_{(1-\alpha/2;n-2)}}$$

$$\frac{13(649{,}546)}{5.01};\qquad \frac{13(649{,}546)}{24.7}$$

$$1{,}685{,}449 \geq \sigma^2_{y|x} \geq 341{,}866$$

(4) Interval such that the probability is 0.95 that the value of tensile strength for a Brinell hardness of 105.0 will be in this interval.

$$b_0 + b_1x^* \pm t_{(\alpha/2;n-2)}s_{y|x}\sqrt{1 + \frac{1}{n} + \frac{(x^* - \bar{x})^2}{\sum (x_i - \bar{x})^2}}$$

$$39{,}111.1 \pm 2.160(844.59)$$

$$37{,}286.8 \leq \text{tensile strength} \leq 40{,}935.4$$

If we wished to estimate hardness from tensile strength, we would have simply reversed the roles of x and y, since we are working in Case 2.

5.8 RELATIONS BETWEEN SEVERAL VARIABLES

In Arts. 5.1 to 5.7 the problem considered was that of finding a relation which would enable one to predict a variable from a knowledge of some one other variable. However, in many cases several factors are relevant to the prediction of just one variable. The relations between height and weight of individuals is different at different ages and different for men and women; an estimate of weight based on height, age, and sex will be better than one based on height alone. The relation between tensile strength and Rockwell hardness may depend on the density of the specimens. For each hardness-density combination the tensile strength will vary about a certain mean; we are interested in a formula giving the mean for each combination. As in the case of a single variable, it is assumed that the variance will be the same for each combination.

5.8.1 Least-squares equations. Suppose, for example, we are interested in predicting y, and let x_1 and x_2 be the independent variables. Assume that the true underlying relationship is of the form

$$\text{average value of } y = B_0 + B_1x_1 + B_2x_2$$

If we denote the estimates of the B_i by b_i, the least squares estimate is $\tilde{y} = b_0 + b_1x_1 + b_2x_2$, where b_1 and b_2 are found from the following set of equations:

$$\sum_{i=1}^{n} (y_i - \bar{y})(x_{1i} - \bar{x}_1) = b_1 \sum_{i=1}^{n} (x_{1i} - \bar{x}_1)^2 + b_2 \sum_{i=1}^{n} (x_{1i} - \bar{x}_1)(x_{2i} - \bar{x}_2)$$

$$\sum_{i=1}^{n} (y_i - \bar{y})(x_{2i} - \bar{x}_2) = b_1 \sum_{i=1}^{n} (x_{1i} - \bar{x}_1)(x_{2i} - \bar{x}_2) + b_2 \sum_{i=1}^{n} (x_{2i} - \bar{x}_2)^2 .$$

$$b_0 = \bar{y} - b_1\bar{x}_1 - b_2\bar{x}_2$$

These equations are known as normal equations and can be solved by solving the first for b_1 in terms of b_2 and substituting this expression for b_1 in the sec-

ond, or by any other method. In general, we might consider a regression equation of the sort

$$\text{average value of } y = B_0 + B_1x_1 + B_2x_2 + \ldots + B_kx_k$$

with estimates

$$\tilde{y} = b_0 + b_1x_1 + b_2x_2 + \ldots + b_kx_k$$

where $b_1, b_2, \ldots, b_k$ are found by the solution of a set of k simultaneous equations in k unknowns. For $k = 2$ and 3, detailed instructions are given in Tables 13.34 and 13.35.

5.9 TEST OF SIGNIFICANCE

There are many hypotheses which we might be interested in testing, but the most important question is whether the independent variables taken as a whole lead to an improvement in our ability to forecast y.

For $k = 2$. This is equivalent to testing the hypothesis that $(B_1,B_2) = (0,0)$, i.e., mean value of $y = B_0$. The results may be arranged into Table 13.32,

TABLE 13.32 REGRESSION TABLE FOR $k = 2$

Variation	Sum of squares	Degrees of freedom	Mean square
Due to regression	$b_1c_1 + b_2c_2$	2	$(b_1c_1 + b_2c_2)/2$
About regression	$\sum_{i=1}^{n} (y_i - \tilde{y}_i)^2$	$n - 3$	$\sum_{i=1}^{n} (y_i - \tilde{y}_i)^2/(n - 3)$
Total	$\sum_{i=1}^{n} (y_i - \bar{y})^2$	$n - 1$	

where c_1 and c_2 are defined in the computational Table 13.34 and $\sum_{i=1}^{n}(y_i - \tilde{y}_i)^2$ is obtained by subtraction.★ Reject the hypothesis that $(B_1,B_2) = (0,0)$ if

$$F = \frac{(b_1c_1 + b_2c_2)/2}{\sum_{i=1}^{n} (y_i - \tilde{y}_i)^2/(n - 3)} \geq F_{\alpha;2,n-3}$$

where $F_{\alpha;2,n-3}$ is the α percentage point of the F distribution found in Table 13.27.

For $k = 3$. To test H_0: $(B_1,B_2,B_3) = (0,0,0)$, arrange the results into Table 13.33,

★ The following is an identity:

$$\sum_{i=1}^{n} (y_i - \bar{y})^2 = b_1c_1 + b_2c_2 + \sum_{i=1}^{n} (y_i - \tilde{y}_i)^2$$

TABLE 13.33 REGRESSION TABLE FOR $k = 3$

Variation	Sum of squares	Degrees of freedom	Mean square
Due to regression	$b_1c_1 + b_2c_2 + b_3c_3$	3	$(b_1c_1 + b_2c_2 + b_3c_3)/3$
About regression	$\sum_{i=1}^{n} (y_i - \hat{y}_i)^2$	$n - 4$	$\sum_{i=1}^{n} (y_i - \hat{y}_i)^2/(n - 4)$
Total	$\sum_{i=1}^{n} (y_i - \bar{y})^2$	$n - 1$	

where c_1, c_2, and c_3 are defined in the computational Table 13.35 and $\sum_{i=1}^{n} (y_i - \hat{y}_i)^2$ is obtained by subtraction.*

Reject the hypothesis that $(B_1,B_2,B_3) = (0,0,0)$ if

$$F = \frac{(b_1c_1 + b_2c_2 + b_3c_3)/3}{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2/(n - 4)} \geq F_{\alpha;3,n-4}$$

where $F_{\alpha;3,n-4}$ is the α percentage point of the F distribution found in Table 13.27.

5.10 NONLINEAR REGRESSION

Nonlinear regression falls into the above model. For example,

$$\text{average value of } y = B_0 + B_1Z + B_2Z^2$$

Since the Z's are fixed variables, we can write the quadratic equation in the form

$$\text{average value of } y = B_0 + B_1x_1 + B_2x_2$$

where $x_1 = Z$ and $x_2 = Z^2$. Hence the least squares estimate of the B's can be obtained using the procedure presented above. (See Tables 13.34 and 13.35.)

5.11 EXAMPLE

During the years 1951 and 1952, the County of Santa Clara, in California, contracted for a cloud-seeding operation.† In order to evaluate the effectiveness of this operation, the county and the surrounding area were di-

* The following is an identity:

$$\sum_{i=1}^{n} (y_i - \bar{y})^2 = b_1c_1 + b_2c_2 + b_3c_3 + \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

† G. J. Lieberman, *An Evaluation of the 1951-1952 Cloud Seeding Experiment in Santa Clara County*, Stanford University, Stanford, California.

vided geographically into regions. The rainfall in the Los Gatos, Palo Alto, and Santa Clara (y) region was to be predicted from the rainfall in the Berkeley, Crockett, Oakland, San Francisco area (x_1), the Merced, Modesto, and Stockton area (x_2), and the Big Sur, Coalinga, King City, and Paso Robles area (x_3). These areas were determined in such a manner that they contained long-record stations, and all the stations within a group were geographically located close to one another. In making this rainfall study, storm totals, summed

TABLE **13.34** COMPUTATIONAL SCHEME FOR SOLVING THE NORMAL EQUATIONS

$$\bar{y} = b_0 + b_1x_1 + b_2x_2$$

The normal equations presented in Art. 5.8 are of the form

$$a_{11}b_1 + a_{12}b_2 = c_1; \qquad a_{21}b_1 + a_{22}b_2 = c_2$$

where

$$a_{11} = \sum_{i=1}^{n} (x_{1_i} - \bar{x}_1)^2 = \sum_{i=1}^{n} x_{1_i}^2 - n\bar{x}_1^2 = \text{———}$$

$$a_{21} = a_{12} = \sum_{i=1}^{n} (x_{1_i} - \bar{x}_1)(x_{2_i} - \bar{x}_2) = \sum_{i=1}^{n} x_{1_i}x_{2_i} - n\bar{x}_1\bar{x}_2 = \text{———}$$

$$a_{22} = \sum_{i=1}^{n} (x_{2_i} - \bar{x}_2)^2 = \sum_{i=1}^{n} x_{2_i}^2 - n\bar{x}_2^2 = \text{———}$$

$$c_1 = \sum_{i=1}^{n} (x_{1_i} - \bar{x}_1)(y_i - \bar{y}) = \sum_{i=1}^{n} x_{1_i}y_i - n\bar{x}_1\bar{y} = \text{———}$$

$$c_2 = \sum_{i=1}^{n} (x_{2_i} - \bar{x}_2)(y_i - \bar{y}) = \sum_{i=1}^{n} x_{2_i}y_i - n\bar{x}_2\bar{y} = \text{———}$$

operation	b_1	b_2	c	check
(1)	a_{11}	a_{12}	c_1	$a_{11} + a_{12} + c_1$
(2)	a_{21}	a_{22}	c_2	$a_{21} + a_{22} + c_2$
(3) (1) repeated	μ_{11}	μ_{12}	μ_{13}	
(4) (3) divided by a_{11}	1	V_{12}	V_{13}	
(5) (2) $- V_{12} \times$ (3)	0	μ_{22}	μ_{23}	
(6) (5) divided by μ_{22}	0	1	V_{23}	

Solution

(7) $b_2 = V_{23}$

(8) $b_1 = V_{13} - V_{12}b_2$

(9) $b_0 = \bar{y} - b_1\bar{x}_1 - b_2\bar{x}_2$

The check is started with line 3. All the operations from line 3 on are performed on the values in the check column. For each line, then, the sum of the entries in all the columns should check with the entry in the check column.

TABLE **13.35** COMPUTATIONAL SCHEME FOR SOLVING THE NORMAL EQUATIONS

$$\bar{y} = b_0 + b_1x_1 + b_2x_2 + b_3x_3$$

The normal equations are of the form:

$$a_{11}b_1 + a_{12}b_2 + a_{13}b_3 = c_1$$
$$a_{21}b_1 + a_{22}b_2 + a_{23}b_3 = c_2$$
$$a_{31}b_1 + a_{32}b_2 + a_{33}b_3 = c_3$$

where

$$a_{11} = \sum_{i=1}^{n} (x_{1_i} - \bar{x}_1)^2 = \sum_{i=1}^{n} x_{1_i}^2 - n\bar{x}_1^2 = \text{\_\_\_\_\_}$$

$$a_{21} = a_{12} = \sum_{i=1}^{n} (x_{1_i} - \bar{x}_1)(x_{2_i} - \bar{x}_2) = \sum_{i=1}^{n} x_{1_i}x_{2_i} - n\bar{x}_1\bar{x}_2 = \text{\_\_\_\_\_}$$

$$a_{22} = \sum_{i=1}^{n} (x_{2_i} - \bar{x}_2)^2 = \sum_{i=1}^{n} x_{2_i}^2 - n\bar{x}_2^2 = \text{\_\_\_\_\_}$$

$$a_{13} = a_{31} = \sum_{i=1}^{n} (x_{1_i} - \bar{x}_1)(x_{3_i} - \bar{x}_3) = \sum_{i=1}^{n} x_{1_i}x_{3_i} - n\bar{x}_1\bar{x}_3 = \text{\_\_\_\_\_}$$

$$a_{23} = \sum_{i=1}^{n} (x_{2_i} - \bar{x}_2)(x_{3_i} - \bar{x}_3) = \sum_{i=1}^{n} x_{2_i}x_{3_i} - n\bar{x}_2\bar{x}_3 = \text{\_\_\_\_\_}$$

$$a_{33} = \sum_{i=1}^{n} (x_{3_i} - \bar{x}_3)^2 = \sum_{i=1}^{n} x_{3_i}^2 - n\bar{x}_3^2 = \text{\_\_\_\_\_}$$

$$c_1 = \sum_{i=1}^{n} (x_{1_i} - \bar{x}_1)(y_i - \bar{y}) = \sum_{i=1}^{n} x_{1_i}y_i - n\bar{x}_1\bar{y} = \text{\_\_\_\_\_}$$

$$c_2 = \sum_{i=1}^{n} (x_{2_i} - \bar{x}_2)(y_i - \bar{y}) = \sum_{i=1}^{n} x_{2_i}y_i - n\bar{x}_2\bar{y} = \text{\_\_\_\_\_}$$

$$c_3 = \sum_{i=1}^{n} (x_{3_i} - \bar{x}_3)(y_i - \bar{y}) = \sum_{i=1}^{n} x_{3_i}y_i - n\bar{x}_3\bar{y} = \text{\_\_\_\_\_}$$

Operation	b_1	b_2	b_3	c	Check
(1)	a_{11}	a_{12}	a_{13}	c_1	$a_{11} + a_{12} + a_{13} + c_1$
(2)	a_{21}	a_{22}	a_{23}	c_2	$a_{21} + a_{22} + a_{23} + c_2$
(3)	a_{31}	a_{32}	a_{33}	c_3	$a_{31} + a_{32} + a_{33} + c_3$
(4) (1) repeated	μ_{11}	μ_{12}	μ_{13}	μ_{14}	
(5) (4) divided by a_{11}	1	V_{12}	V_{13}	V_{14}	
(6) (2) $- V_{12} \times$ (4)	0	μ_{22}	μ_{23}	μ_{24}	
(7) (6) divided by μ_{22}	0	1	V_{23}	V_{24}	
(8) (3) $- V_{13} \times$ (4) $- V_{23} \times$ (6)	0	0	μ_{33}	μ_{34}	
(9) (8) divided by μ_{33}	0	0	1	V_{34}	

solution

(10) $b_3 = V_{34}$

(11) $b_2 = V_{24} - V_{23}b_3$

(12) $b_1 = V_{14} - b_3V_{13} - b_2V_{12}$

(13) $b_0 = \bar{y} - b_1\bar{x}_1 - b_2\bar{x}_2 - b_3\bar{x}_3$

The check is started with line 4. All the operations from line 4 on are performed on the values in the check column. For each line, then, the sum of the entries in all the columns should check with the entry in the check column.

over all rainfall stations within an area, were chosen as the index to be considered. From preliminary analysis it was determined that the cube root of the total rainfall over all the stations within a region in the county, per storm, can be predicted from a linear combination of the cube roots of the total rainfall over all the stations within a region in the control area, per storm, i.e.,

$$\text{average value of } y = B_0 + B_1x_1 + B_2x_2 + B_3x_3$$

From past data, these coefficients were estimated so that

$$\tilde{y} = b_0 + b_1x_1 + b_2x_2 + b_3x_3$$

Assuming no seeding effect in the areas outside the county, the rainfall within the county can be predicted from the above relationship, during the seeding period, and compared with the actual values. If seeding is effective, we should expect the actual rainfall for seeded storms to exceed the predicted values rather consistently.

The data is as follows:

$n = 168;\quad \sum_{i=1}^{168} x_{1_i}y_i = 332.176315;\quad \sum_{i=1}^{168} x_{3_i}^2 = 349.784479$

$\bar{x}_1 = 1.37761;\quad \sum_{i=1}^{168} x_{2_i}y_i = 251.280625;\quad \sum_{i=1}^{168} x_{1_i}x_{2_i} = 284.67716$

$\bar{x}_2 = 1.05103;\quad \sum_{i=1}^{168} x_{3_i}y_i = 315.567472;\quad \sum_{i=1}^{168} x_{1_i}x_{3_i} = 352.654387$

$\bar{x}_3 = 1.27261;\quad \sum_{i=1}^{168} x_{1_i}^2 = 384.327981;\quad \sum_{i=1}^{168} x_{2_i}x_{3_i} = 270.377485$

$\bar{y} = 1.20063;\quad \sum_{i=1}^{168} x_{2_i}^2 = 221.509607;\quad \sum_{i=1}^{168} y_i^2 = 296.885778$

$\sum_{i=1}^{168} x_{1_i}^2 - n\bar{x}_1^2 = 65.494584;\quad \sum_{i=1}^{168} x_{1_i}x_{2_i} - n\bar{x}_1\bar{x}_2 = 41.428439$

$\sum_{i=1}^{168} x_{1_i}x_{3_i} - n\bar{x}_1\bar{x}_3 = 58.122085;\quad \sum_{i=1}^{168} x_{2_i}^2 - n\bar{x}_2^2 = 35.926129$

$\sum_{i=1}^{168} x_{2_i}x_{3_i} - n\bar{x}_2\bar{x}_3 = 45.668373;\quad \sum_{i=1}^{168} x_{3_i}^2 - n\bar{x}_3^2 = 77.701072$

$\sum_{i=1}^{168} x_{1_i}y_i - n\bar{x}_1\bar{y} = 54.303488;\quad \sum_{i=1}^{168} x_{2_i}y_i - n\bar{x}_2\bar{y} = 39.281616$

$\sum_{i=1}^{168} x_{3_i}y_i - n\bar{x}_3\bar{y} = 58.873775$

Operation	b_1	b_2	b_3	c	Check
(1)	65.494584	41.428439	58.122085	54.303488	219.348596
(2)	41.428439	35.926129	45.668373	39.281616	162.304551
(3)	58.122085	45.668373	77.701072	58.873775	240.365305
(4) (1) repeated	65.494584	41.428439	58.122085	54.303488	219.348596
(5) (4) divided by 65.494584	1	0.63254756	0.88743346	0.82912944	3.34911046
(6) (2) −0.63254756 × (4)	0	9.720671	8.903390	4.932078	23.556139
(7) (6) divided by 9.720671	0	1	0.9159234	0.5073804	2.4233038
(8) (3) −0.88743346 (4) −0.9159234 × (6)	0	0	17.966766	6.165637	24.132403

(9) (8) divided by 17.966766   0   0   1   0.3431690   1.3431690

(10) $b_3 = 0.3431690$

(11) $b_2 = 0.5073804 - (0.9159234)(0.3431690)$
$= 0.1930639$

(12) $b_1 = 0.82912944 - (0.88743346)(0.3431690)$
$- (0.63254756)(0.1930639) = 0.4024677$

(13) $b_0 = 1.20063 - (0.4024677)(1.37761) - (0.1930639)(1.05103)$
$- (0.3431690)(1.37761) = 0.60655$

Equation:

$$\hat{y} = 0.0066 + 0.4025x_1 + 0.1931x_2 + 0.3432x_3$$

6. ANALYSIS OF VARIANCE

6.1 INTRODUCTION

In Art. 4, the problem of testing whether two means are equal was considered. The t test was used for making such a comparison. This problem is actually a special case of the more general problem of comparing several means. A possible solution to this general problem is to enumerate every possible pair, and test whether each pair differs by means of the t test. The disadvantage of this procedure is clear upon a little reflection. Even if the population mean is the same for every sample mean, we must expect that if there are enough sample means some will be extremely large and some extremely small. This will lead to one or more fictitious significant differences —with probability much higher than α. This distortion in the significance level introduces another difficulty. Suppose that the 45 possible comparisons among ten means have all been made, and four are significant by an 0.05 level t test; the experimenter must now wonder *which* (if any) of these 4 significant differences are really indicative of true differences.

The appropriate solution to the problem is the analysis of variance. The analysis of variance, however, has a much wider application than this simple generalization, and is probably the most powerful procedure in the field of experimental statistics. In this article, three problems will be treated: (1) A test for homogeneity of means will be given. (2) If the hypothesis of homogeneity is rejected, a procedure for comparing the means will be given. (3) Estimates of the variability due to a particular effect will be found.

6.2 ONE-WAY CLASSIFICATION

Suppose four different quantities of carbon are to be added to a batch of raw material in the manufacture of steel. Six specimens are taken for each of the four quantities, and it is desired to determine the effect of these percentages on the tensile stress of the resultant steel. The data are given in Table 13.36.

TABLE 13.36 TENSILE STRENGTH OF HOT ROLLED STEEL FOR DIFFERENT PERCENTAGE OF CARBON

								$\bar{x}$
Percentage 1	0.10%	23050	36000	31100	32650	30900	31400	30850
Percentage 2	0.20%	41850	25650	46700	34500	36650	31450	36133
Percentage 3	0.40%	47050	43450	43000	38650	41850	35450	41575
Percentage 4	0.60%	49650	73900	66450	74550	62400	63750	65117

It is reasonable to assume that the tensile strength of a specimen consists of the sum of two components; namely, the population mean effect attributed to the addition of the particular percentage of carbon, and a random effect. The random effects are assumed to be independently normally distributed with mean 0 and variance σ^2. Thus, the third specimen having 0.20% of carbon has a tensile strength:

$$46700 = \text{population mean effect due to } 0.20\% \text{ carbon} + \text{random effect}$$

All the specimens having 0.20% carbon have the same mean effect and differ only because of the random effect. More generally, these assumptions can be summarized as follows:

$$X_{ij} = \zeta_i + \epsilon_{ij}$$

where

X_{ij} is the outcome of the jth specimen corresponding to the ith treatment; $i = 1, 2, \ldots, r; j = 1, 2, \ldots, s$;
ζ_i is the population mean effect attributed to the ith treatment;
ϵ_{ij} is the random effect assumed to be independently normally distributed with mean 0 and variance σ^2.

A few words about the selection of the specimens of carbon steel to be used in the experiment are in order. The tensile strength of steel depends on many factors besides the percentage of carbon—the temperature, presence of other alloys, and so forth. It is important in running experiments to determine the effect of carbon on a particular kind of steel to make sure that differences which are asserted to be due to carbon do not arise from some other factors, say all the 0.10% carbon bars were treated at a higher temperature than the others. In some cases other factors which affect the steel may be isolated as factors in the experiment and their effect removed by the techniques of two-way, three-way, and other analysis of variance techniques discussed in the subsequent articles. If this is not done, the specimens to be used with each percentage of carbon should be chosen at random with respect to the other factors which are not specified; this random choice will insure that the conclusions are not vitiated by a coincidence of effects. A table of random numbers is useful in assigning specimens to the specific treatments.

6.2.1 Test for homogeneity. A major problem arising in the analysis of variance is to test the hypothesis that r means are equal, i.e., to test whether all the carbon effects are the same in the example.

This hypothesis can be written as H_0: $\zeta_1 = \zeta_2 = \zeta_3 = \ldots = \zeta_r$, and may

TABLE **13.37** ANALYSIS OF VARIANCE TABLES, ONE-WAY CLASSIFICATION

Source	Sum of squares	Degrees of freedom	Mean square	Average mean square	Test
Between treatments	$SS_1 = s\sum_{i=1}^{r}(\bar{X}_{i\cdot} - \bar{X}_{\cdot\cdot})^2$	$r - 1$	$SS^*_1 = SS_1/(r-1)$	$\sigma^2 + \frac{s\sum_{i=1}^{r}(\zeta_i - \bar{\zeta})^2}{r-1}$	$F = \frac{SS^*_1}{SS^*_2}$
Within treatments	$SS_2 = \sum_{i=1}^{r}\sum_{j=1}^{s}(X_{ij} - \bar{X}_{i\cdot})^2$	$r(s-1)$	$SS^*_2 = SS_2/r(s-1)$	σ^2	
Total	$SS = \sum_{i=1}^{r}\sum_{j=1}^{s}(X_{ij} - \bar{X}_{\cdot\cdot})^2$	$rs - 1$	$SS^* = SS/(rs-1)$	$\sigma^2 + \frac{s\sum_{i=1}^{r}(\zeta_i - \bar{\zeta})^2}{rs-1}$	

In this table $\bar{X}_{i\cdot} = \sum_{j=1}^{s}\frac{X_{ij}}{s}$; $\bar{X}_{\cdot\cdot} = \sum_{i=1}^{r}\sum_{j=1}^{s}\frac{X_{ij}}{rs}$; $\bar{\zeta} = \sum_{i=1}^{r}\frac{\zeta_i}{r}$

be answered by making complete the analysis of variance table, Table 13.37.

Computational procedure

(1) Calculate totals for each treatment.

$$R_1, R_2, \ldots, R_r$$

(2) Calculate over-all total.

$$T = R_1 + R_2 + \ldots + R_r$$

(3) Compute crude total sum of squares.

$$\sum_{i=1}^{r} \sum_{j=1}^{s} X_{ij}^2 = X_{11}^2 + X_{12}^2 + \ldots + X_{rs}^2$$

(4) Calculate crude sum of squares between treatments.

$$\frac{\sum_{i=1}^{r} R_i^2}{s} = (R_1^2 + R_2^2 + \ldots + R_r^2)/s$$

(5) Calculate correction factor due to mean $= T^2/rs$.

From the above quantities compute

(6) $SS_3 = (4) - (5) = \sum_{i=1}^{r} R_i^2/s - \frac{T^2}{rs}$

(7) $SS = (3) - (5) = \sum_{i=1}^{r} \sum_{j=1}^{s} X_{ij}^2 - \frac{T^2}{rs}$

(8) $SS_2 = (7) - (6) = SS - SS_3$

If
$$F = \frac{SS_3/(r-1)}{SS_2/r(s-1)} = \frac{SS_3^*}{SS_2^*} \geq F_{\alpha;r-1,r(s-1)}$$

we reject the hypothesis

$$\zeta_1 = \zeta_2 = \zeta_3 = \ldots = \zeta_r$$

where $F_{\alpha;r-1,r(s-1)}$ is the upper α percentage point of the F distribution given in Table 13.27.

6.2.2 Test for comparisons of mean. If the hypothesis

$$H_0: \zeta_1 = \zeta_2 = \zeta_3 = \ldots = \zeta_r$$

is rejected, it is possible to make statements about which means differ. For a long time there was no satisfactory solution to this problem. However, Tukey* and Scheffé† have presented solutions whereby it becomes possible to make contrasts of the form $\zeta_k - \zeta_l$. Tukey's procedure leads to probability statements in the form of confidence intervals for the contrasts

* J Tukey, *Allowances for Various Types of Error Rates*, unpublished invited address presented before a joint meeting of the Institute of Mathematical Statistics and the Eastern North American Region of the Biometric Society on March 19, 1952, at Blacksburg, Va.

† H. Scheffé, "A Method for Judging All Contrasts in the Analysis of Variance," *Biometrika*, Vol. 40, June 1953.

TABLE **13.38** TABLE OF FACTORS c^* (5% Significance Level)★

p \ n[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	18.0	26.7	32.8	37.2	40.5	43.1	45.4	47.3	49.1	50.6	51.9	53.2	54.3	55.4	56.3	57.2	58.0	58.8	59.6
2	6.09	8.28	9.80	10.89	11.73	12.43	13.03	13.54	13.99	14.39	14.75	15.08	15.38	15.65	15.91	16.14	16.36	16.57	16.77
3	4.50	5.89	6.83	7.51	8.04	8.47	8.85	9.18	9.46	9.72	9.95	10.16	10.35	10.52	10.69	10.84	10.98	11.12	11.24
4	3.93	5.00	5.76	6.31	6.73	7.06	7.35	7.60	7.83	8.03	8.21	8.37	8.52	8.67	8.80	8.92	9.03	9.14	9.24
5	3.64	4.60	5.22	5.67	6.03	6.33	6.58	6.80	6.99	7.17	7.32	7.47	7.60	7.72	7.83	7.93	8.03	8.12	8.21
6	3.46	4.34	4.90	5.31	5.63	5.89	6.12	6.32	6.49	6.65	6.79	6.92	7.04	7.14	7.24	7.34	7.43	7.51	7.59
7	3.34	4.16	4.68	5.06	5.36	5.61	5.82	6.00	6.16	6.30	6.43	6.55	6.66	6.76	6.85	6.94	7.02	7.09	7.17
8	3.26	4.04	4.53	4.89	5.17	5.40	5.60	5.77	5.92	6.05	6.18	6.29	6.39	6.48	6.57	6.65	6.73	6.80	6.87
9	3.20	3.95	4.42	4.76	5.02	5.24	5.43	5.60	5.74	5.87	5.98	6.09	6.19	6.28	6.36	6.44	6.51	6.58	6.65
10	3.15	3.88	4.33	4.66	4.91	5.12	5.30	5.46	5.60	5.72	5.83	5.93	6.03	6.12	6.20	6.27	6.34	6.41	6.47
11	3.11	3.82	4.26	4.58	4.82	5.03	5.20	5.35	5.49	5.61	5.71	5.81	5.90	5.98	6.06	6.14	6.20	6.27	6.33
12	3.08	3.77	4.20	4.51	4.75	4.95	5.12	5.27	5.40	5.51	5.61	5.71	5.80	5.88	5.95	6.02	6.09	6.15	6.21
13	3.06	3.73	4.15	4.46	4.69	4.88	5.05	5.19	5.32	5.43	5.53	5.63	5.71	5.79	5.86	5.93	6.00	6.06	6.11
14	3.03	3.70	4.11	4.41	4.64	4.83	4.99	5.13	5.25	5.36	5.46	5.56	5.64	5.72	5.79	5.86	5.92	5.98	6.03
15	3.01	3.67	4.08	4.37	4.59	4.78	4.94	5.08	5.20	5.31	5.40	5.49	5.57	5.65	5.72	5.79	5.85	5.91	5.96
16	3.00	3.65	4.05	4.34	4.56	4.74	4.90	5.03	5.15	5.26	5.35	5.44	5.52	5.59	5.66	5.73	5.79	5.84	5.90
17	2.98	3.62	4.02	4.31	4.52	4.70	4.86	4.99	5.11	5.21	5.31	5.39	5.47	5.55	5.61	5.68	5.74	5.79	5.84
18	2.97	3.61	4.00	4.28	4.49	4.67	4.83	4.96	5.07	5.17	5.27	5.35	5.43	5.50	5.57	5.63	5.69	5.74	5.79
19	2.96	3.59	3.98	4.26	4.47	4.64	4.79	4.92	5.04	5.14	5.23	5.32	5.39	5.46	5.53	5.59	5.65	5.70	5.75
20	2.95	3.58	3.96	4.24	4.45	4.62	4.77	4.90	5.01	5.11	5.20	5.28	5.36	5.43	5.50	5.56	5.61	5.66	5.71
24	2.92	3.53	3.90	4.17	4.37	4.54	4.68	4.81	4.92	5.01	5.10	5.18	5.25	5.32	5.38	5.44	5.50	5.55	5.59
30	2.89	3.48	3.84	4.11	4.30	4.46	4.60	4.72	4.83	4.92	5.00	5.08	5.15	5.21	5.27	5.33	5.38	5.43	5.48
40	2.86	3.44	3.79	4.04	4.23	4.39	4.52	4.63	4.74	4.82	4.90	4.98	5.05	5.11	5.17	5.22	5.27	5.32	5.36
60	2.83	3.40	3.74	3.98	4.16	4.31	4.44	4.55	4.65	4.73	4.81	4.88	4.94	5.00	5.06	5.11	5.15	5.20	5.24
120	2.80	3.36	3.69	3.92	4.10	4.24	4.36	4.47	4.56	4.64	4.71	4.78	4.84	4.90	4.95	5.00	5.04	5.09	5.13
∞	2.77	3.32	3.63	3.86	4.03	4.17	4.29	4.39	4.47	4.55	4.62	4.68	4.74	4.80	4.84	4.89	4.93	4.97	5.01

[a] Here n is the number of effects being studied

★ This table is taken by permission from Joyce M. May, "Extended and Corrected Tables of the Upper Percentage Points of the Studentised Range," *Biometrika*, Vol 39, Parts 1 and 2, May 1952, p. 192; and from H. O. Hartley, "Corrigenda to Tables of Percentage Points of the Studentized Range," *Biometrika*, Vol. 40, Parts 1 and 2, June 1953, p. 236.

TABLE **13.39** TABLE OF FACTORS c^* (1% Significance Level)*

ν \ n[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	90.0	134	164	186	202	216	227	237	246	253	260	266	272	277	232	286	291	295	298
2	14.0	18.9	22.3	24.7	26.6	28.2	29.5	30.7	31.7	32.6	33.4	34.2	34.8	35.5	36.0	36.5	37.0	37.5	38.0
3	8.26	10.56	12.17	13.34	14.25	15.00	15.65	16.20	16.69	17.13	17.53	17.89	18.23	18.54	18.83	19.09	19.33	19.56	19.79
4	6.51	8.08	9.17	9.97	10.58	11.10	11.55	11.93	12.26	12.56	12.84	13.09	13.32	13.53	13.73	13.92	14.09	14.25	14.40
5	5.70	6.97	7.80	8.42	8.91	9.32	9.67	9.97	10.24	10.48	10.70	10.89	11.08	11.24	11.40	11.55	11.68	11.81	11.93
6	5.24	6.32	7.03	7.56	7.97	8.31	8.61	8.87	9.10	9.30	9.49	9.65	9.81	9.95	10.08	10.21	10.32	10.43	10.54
7	4.95	5.92	6.54	7.01	7.37	7.68	7.94	8.17	8.37	8.55	8.71	8.86	9.00	9.12	9.24	9.35	9.46	9.55	9.65
8	4.74	5.63	6.20	6.63	6.96	7.24	7.47	7.68	7.86	8.03	8.18	8.31	8.44	8.55	8.66	8.76	8.86	8.95	9.03
9	4.60	5.42	5.96	6.35	6.66	6.91	7.13	7.33	7.50	7.65	7.79	7.91	8.02	8.13	8.23	8.33	8.41	8.50	8.58
10	4.48	5.26	5.77	6.14	6.43	6.67	6.88	7.06	7.22	7.36	7.49	7.60	7.71	7.81	7.91	7.99	8.08	8.15	8.23
11	4.39	5.14	5.62	5.98	6.25	6.47	6.67	6.84	6.99	7.13	7.25	7.36	7.46	7.56	7.65	7.73	7.81	7.88	7.95
12	4.32	5.04	5.50	5.84	6.10	6.32	6.51	6.67	6.81	6.94	7.06	7.17	7.26	7.36	7.44	7.52	7.60	7.67	7.73
13	4.26	4.96	5.40	5.73	5.98	6.19	6.37	6.53	6.67	6.79	6.90	7.01	7.10	7.19	7.27	7.35	7.42	7.49	7.55
14	4.21	4.89	5.32	5.64	5.88	6.08	6.26	6.41	6.54	6.66	6.77	6.87	6.96	7.05	7.13	7.20	7.27	7.34	7.40
15	4.17	4.83	5.25	5.56	5.80	5.99	6.16	6.31	6.44	6.55	6.66	6.76	6.85	6.93	7.00	7.07	7.14	7.20	7.26
16	4.13	4.78	5.19	5.49	5.72	5.91	6.08	6.22	6.35	6.46	6.56	6.66	6.74	6.82	6.90	6.97	7.03	7.09	7.15
17	4.10	4.73	5.14	5.43	5.66	5.85	6.01	6.15	6.27	6.38	6.48	6.57	6.66	6.73	6.81	6.87	6.94	7.00	7.05
18	4.07	4.70	5.09	5.38	5.60	5.79	5.95	6.08	6.20	6.31	6.41	6.50	6.58	6.65	6.73	6.79	6.85	6.91	6.97
19	4.05	4.66	5.05	5.34	5.55	5.73	5.89	6.02	6.14	6.25	6.34	6.43	6.51	6.58	6.65	6.72	6.78	6.84	6.89
20	4.02	4.63	5.02	5.30	5.51	5.69	5.84	5.97	6.09	6.19	6.28	6.37	6.45	6.52	6.59	6.66	6.71	6.77	6.82
24	3.96	4.54	4.91	5.17	5.37	5.54	5.69	5.81	5.92	6.02	6.11	6.19	6.26	6.33	6.39	6.45	6.51	6.57	6.61
30	3.89	4.45	4.80	5.05	5.24	5.40	5.53	5.65	5.76	5.85	5.93	6.01	6.08	6.14	6.20	6.26	6.31	6.36	6.41
40	3.82	4.36	4.70	4.93	5.11	5.26	5.39	5.50	5.60	5.69	5.77	5.84	5.90	5.96	6.02	6.07	6.12	6.17	6.21
60	3.76	4.28	4.60	4.82	4.99	5.13	5.25	5.36	5.45	5.53	5.60	5.67	5.73	5.78	5.83	5.88	5.93	5.98	6.01
120	3.70	4.20	4.50	4.71	4.87	5.00	5.12	5.21	5.30	5.38	5.44	5.50	5.56	5.61	5.66	5.71	5.75	5.79	5.83
∞	3.64	4.12	4.40	4.60	4.76	4.88	4.99	5.08	5.16	5.23	5.29	5.35	5.40	5.45	5.49	5.53	5.57	5.61	5.64

[a] Here n is the number of effects being studied.

★ This table is taken by permission from May, "Extended and Corrected Tables of the Upper Percentage Points of the Studentised Range"; and from Hartley, "Corrigenda to Tables of Percentage Points of the Studentised Range."

$\zeta_k - \zeta_l$; i.e., the probability is $1 - \alpha$ that the values $\zeta_k - \zeta_l$ for *all* such contrasts ($k = 1, 2, \ldots, r$; $l = 1, 2, \ldots, r$) simultaneously satisfy

$$\bar{X}_{k.} - \bar{X}_{l.} - c \leq \zeta_k - \zeta_l \leq \bar{X}_{k.} - \bar{X}_{l.} + c$$

where c is a factor obtained from Table 13.38 or 13.39 depending on whether $\alpha = 0.05$ or 0.01 and from the analysis of variance table. The means are said to differ significantly when the appropriate confidence interval fails to include 0. Furthermore, if the interval includes only positive values, the difference is said to differ significantly from zero, and to be positive. Similarly, if the confidence interval includes only negative values, the difference is said to differ significantly from zero, and to be negative. If the interval includes 0, the means are said not to differ significantly. Summarizing then, the F test is made for the homogeneity of the means. If this hypothesis is rejected, Tukey's procedure is applied to determine which of the means differ.

A possible short-cut method for determining the homogeneity of all the treatment effects is to check whether $\bar{X}_{\max} - \bar{X}_{\min.} \pm c$ includes 0. If this contrast includes 0, every other contrast of this type includes 0, and hence all the treatment effects are called equal. If the above contrast fails to include zero, the corresponding treatment effects, and perhaps others, differ significantly. This short-cut method has a level of significance exactly equal to α. However, the data in the analysis of variance table are necessary for determining the factor c, and for other results, so that this table should be completed regardless.

The factor c can be obtained from the data in the analysis of variance table and Table 13.38 or 13.39 depending on the level of significance. Table 13.38 or 13.39 is entered with the indices degrees of freedom and the number of treatments studied (r). The proper degrees of freedom are those corresponding to the degrees of freedom of the within treatments source in the analysis of variance table, i.e., $r(s - 1)$. The factor c^* is read from the table; c is obtained from $c = c^*\sqrt{SS_2^*/s}$.

Scheffé's procedure also leads to confidence statements and if we apply his test when the F test of homogeneity is rejected, the level of significance is preserved. On the other hand, if we apply Tukey's test when the F test of homogeneity is rejected, we increase the significance level *slightly*. However, if the only type of comparison of interest has the form $\zeta_k - \zeta_l$, Tukey's procedure will result in shorter confidence intervals for $\zeta_k - \zeta_l$ than would Scheffé's procedure.* Consequently, we are going to use the Tukey method, and proceed as if the significance level suffered a negligible increase.

6.2.3 Estimating the variability due to the sources. In the analysis of variance table there is a column headed "Average mean square." Estimates of these quantities are given in the column headed "Mean square." If all the treatment means are equal, the entries in the "Average mean square" column would be σ^2. Consequently, it is expected, if all the means are equal, that the estimates given in the "Mean square" column will be close together. On the

* If other type of contrasts are also desired, e.g., $(\zeta_1 + \zeta_2 + \zeta_3)/3 - (\zeta_4 + \zeta_5 + \zeta_6)/3$, Scheffé's procedure should be used.

other hand, if the treatments are in fact different, then the average value of the mean square for treatments will be increased by $[s/(r-1)]\sum(\zeta_i - \bar{\zeta})^2$, which will tend to increase the value of F, leading to a significant result and the detection of the differences.

6.2.4 Example. Returning to the data on the tensile strength of carbon steel, the complete analysis of variance table is as follows:

ANALYSIS OF VARIANCE TABLE FOR TENSILE STRENGTH

Source	Sum of squares	Degrees of freedom	Mean square	Average mean square	Test
Between treatments	4,111,498,600	3	1,370,499,533		$F = 31.576$
Within treatments	868,060,500	20	43,403,025		
Total	4,979,559,100	23	216,502,670		

The completed computational procedure is given below:

(1) $R_1, R_2, \ldots, R_r = 185{,}100; 216{,}800; 249{,}450; 390{,}700$

(2) $T = \sum_{i=1}^{4} R_i = 185{,}100 + 216{,}800 + 249{,}450 + 390{,}700 = 1{,}042{,}050$

(3) $$\sum_{i=1}^{4}\sum_{j=1}^{6} x_{ij}^2 = (23{,}050)^2 + (36{,}000)^2 + \ldots + (63{,}750)^2$$
$$= 50{,}224{,}067{,}500$$

(4) $$\frac{\sum_{i=1}^{r} R_i^2}{6} = \frac{(185{,}100)^2 + (216{,}800)^2 + (249{,}450)^2 + (390{,}700)^2}{6}$$
$$= 49{,}356{,}007{,}000$$

(5) $$\frac{T^2}{24} = \frac{1{,}085{,}868{,}202{,}500}{24} = 45{,}244{,}508{,}400$$

(6) $SS_3 = 49{,}356{,}007{,}000 - 45{,}244{,}508{,}400 = 4{,}111{,}498{,}600$

(7) $SS = 50{,}224{,}067{,}500 - 45{,}244{,}508{,}400 = 4{,}979{,}559{,}100$

(8) $SS_2 = 4{,}979{,}559{,}100 - 4{,}111{,}498{,}600 = 868{,}060{,}500$

Since $F_{.05;3,20} = 3.10$ and $F = 31.576 > 3.10$, the hypothesis that $\zeta_1 = \zeta_2 = \zeta_3 = \zeta_4$ is rejected and we conclude that the tensile strengths differ. In order to determine the magnitude of these differences, we compute c for $r = 4$, $r(s-1) = 20$. Here $c^* = 3.96$, where the factor 3.96 is obtained from Table 13.38.

Therefore, $c = 3.96(2689) = 10{,}648$, and any two means differing by this much differ significantly at $\alpha = 0.05$. Thus the following differences are significant.

0.60 from 0.40
0.60 from 0.20
0.60 from 0.10
0.40 from 0.10

Confidence intervals of size 0.95 for the differences can be given, e.g., the confidence interval for difference $\zeta_{.60} - \zeta_{.10}$ is:

$$\bar{X}_{.60} - \bar{X}_{.10} \pm c = 34{,}267 \pm 10{,}648$$

so that

$$23{,}619 \leq \zeta_{.60} - \zeta_{.10} \leq 44{,}915$$

Similarly

$$\bar{X}_{.60} - \bar{X}_{.40} \pm c = 23{,}542 \pm 10{,}648$$

so that

$$12{,}894 \leq \zeta_{.60} - \zeta_{.40} \leq 34{,}190$$

6.2.5 Randomization tests in the analysis of variance. It has been emphasized in the discussion of the t test in the analysis of variance that the random effects are assumed to be normally and independently distributed. These tests actually have a wider justification if they are considered special cases of what are called permutation tests. Suppose, for example, we are interested in testing the difference between two effects, say percentage of carbon, and suppose that the experimenter takes eight samples (let them be named a, b, c, etc.) and chooses four with a table of random numbers to receive treatment A and the other four treatment B. The results of this experiment are:

A		B	
a	2	f	17
h	15	e	19
b	10	c	18
d	9	g	12

He could test the hypothesis that there is no difference between treatments by calculating a t test or an F test, or consider it a one-way analysis of variance, calculating an F with 1 and 6 degrees of freedom; the value of F is 6 in this problem. Suppose he is interested in a level of significance of 0.05. Even if he is unwilling to assume normality, he can obtain a test of the hypothesis as follows: Consider all possible pairs of samples that can be formed with the eight numbers above; there are $\binom{8}{4} = 70$ different ways for the experiment to turn out (one for each way of selecting 4 of the eight numbers for treatment A). If there is no difference between treatments, each of these outcomes is equally likely. Suppose we adopt the procedure that we will reject the hypothesis of equality of treatments if we have one of the samples with the four largest differences in the mean; the probability of rejection when the hypothesis is true is $4/70 = 0.057$, since all 70 possibilities are equally likely. If the hypothesis is false, large differences are more likely.

A partial list of the 70 outcomes (starting with most extreme ones) is:

A				B				difference in means $\bar{x}_A - \bar{x}_B$	F
2	9	10	12	15	17	18	19	−9	14.84
15	17	18	19	2	9	10	12	+9	
2	9	10	15	12	17	18	19	−7.5	6.00
12	17	18	19	2	9	10	15	+7.5	

A				B				difference in means $\bar{x}_A - \bar{x}_B$	F
2	9	10	17	12	15	18	19	−6.5	
12	15	18	19	2	9	10	17	+6.5	
									3.61
2	9	12	15	10	17	18	19	−6.5	
10	17	18	19	2	9	12	15	+6.5	

Observe that only 4 of the 70 possibilities give values of F as large as that in the particular sample obtained.

The significance level of the test is 0.057. If $F = 6$ is looked up in the table it is seen to be significant at the 0.05 level (using the assumption of normality).

This kind of test is called a randomization test. It has the drawback that for medium or large-sized samples the computational burden is enormous. For example, if there are 20 objects divided at random into two groups of 10, then the number of possibilities is $\binom{20}{10} = 184{,}756$, and listing the 5% most extreme cases would be prohibitive.

Both numerical and analytical investigations* have shown, however, that for medium and large samples, the distribution of F obtained through enumeration of the possibilities is closely approximated by the tabulated F distribution. So without assuming normality we *can* test the hypothesis of no treatment effects by making a randomization test, but instead of exactly evaluating the significance level by actual counting we content ourselves with an approximate evaluation, as yielded by the F tables.

6.3 TWO-WAY CLASSIFICATION

The reader is advised to read the section on the one-way classification before going on to this section. Experiments can be conducted in such a way as to study the effects of several variables in the same experiment. For each variable a number of levels may be chosen for study. When observations are made for all possible combinations of levels the experiment is called a factorial experiment. This section is concerned with a factorial experiment where the effects of two variables at several levels are to be studied. For example, W. J. Youden† reports the following experiment. Counts are made on four samples of radium. If the four specimens are run consecutively, the four counts may be called experiment 1. The experiment may be repeated as often as desired, varying the order of the specimens at random in each experiment. The results of this investigation are given in Table 13.40 where the data are given as the net counting rates less 25.00. The experimenter is interested in knowing whether these samples of radium are different. However, it is possible that the line voltage or other conditions that influence the counting rate varies from experiment to experiment.

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* The agreement between the two values 0.05 and 0.057 above is not merely by coincidence.

† W. J. Youden, "The Interpretation of Chemical Data," *Industrial Quality Control*, May 1952.

TABLE 13.40 NEW COUNTING RATES LESS 25.00

Specimen number	Experiment number 1	2	3	4	Specimen average
1	1.46	2.00	1.48	1.51	1.61
2	2.58	3.03	2.82	2.90	2.83
3	4.15	4.61	4.31	4.13	4.30
4	4.54	4.52	4.53	4.15	4.44
Experiment average	3.18	3.54	3.28	3.17	

Thus the model can be written

$$X_{ij} = \zeta_{ij} + \epsilon_{ij}; \qquad i = 1, 2, 3, 4; \; j = 1, 2, 3, 4$$

where

X_{ij} is the counting rate of the ith specimen in the jth experiment;
ζ_{ij} is the population mean counting rate of the ith specimen in the jth experiment;
ϵ_{ij} is the random effect assumed to be normally independently distributed with mean 0 and variance σ^2.

6.3.1 **Interaction.** Before proceeding to make inferences about the structure of the ζ_{ij}, it is useful to refer to Table 13.41, which is a table of population means.

TABLE 13.41 TABLE OF POPULATION MEANS FOR COUNTING RATES

Specimen number	Experiment number 1	2	3	4	Specimen mean	Differences
1	ζ_{11}	ζ_{12}	ζ_{13}	ζ_{14}	ζ_{1}	$\varphi_1 = \zeta_{1.} - \zeta_{..}$
2	ζ_{21}	ζ_{22}	ζ_{23}	ζ_{24}	ζ_{2}	$\varphi_2 = \zeta_{2.} - \zeta_{..}$
3	ζ_{31}	ζ_{32}	ζ_{33}	ζ_{34}	$\zeta_{3.}$	$\varphi_3 = \zeta_{3.} - \zeta_{..}$
4	ζ_{41}	ζ_{42}	ζ_{43}	ζ_{44}	ζ_{4}	$\varphi_4 = \zeta_{4.} - \zeta_{..}$
Experiment mean	ζ_{1}	ζ_{2}	$\zeta_{.3}$	ζ_{4}	$\zeta_{..}$	
Differences	$\gamma_1 = \zeta_{1} - \zeta$	$\gamma_2 = \zeta_{2} - \zeta$	$\gamma_3 = \zeta_{3} - \zeta$	$\gamma_4 = \zeta_{4} - \zeta_{.}$		

Here $\zeta_{i.} = \frac{1}{4}\sum_{j=1}^{4} \zeta_{ij}; \; \zeta_{.j} = \frac{1}{4}\sum_{i=1}^{4} \zeta_{ij}; \; \zeta_{..} = \frac{1}{16}\sum_{i=1}^{4}\sum_{j=1}^{4} \zeta_{ij}$. Thus a mean ζ_{ij} can be written

$$\begin{aligned} \zeta_{ij} &= \zeta_{..} + (\zeta_{i.} - \zeta_{..}) + (\zeta_{.j} - \zeta_{..}) + (\zeta_{ij} - \zeta_{i.} - \zeta_{.j} + \zeta_{..}) \\ &= \zeta_{..} + \varphi_i + \gamma_j + \eta_{ij} \end{aligned}$$

where $\eta_{ij} = \zeta_{ij} - \zeta_{i.} - \zeta_{.j} + \zeta_{..}$ and is known as the interaction term. We say that an interaction between two effects, φ_i and γ_j, exists if the joint

effect of the two taken simultaneously is different from the sum of their separate effects. Thus either lye or muriatic acid may be an effective cleanser, but taken together they are ineffective, and would be said to interact. Or again, suppose there are five machines together with four workmen and it is desired to test whether machines differ in the number of units produced per day. It is quite possible that the second man may work better on the third machine than any other machine because he has worked for 20 years on such a machine. The resultant increased production cannot be assumed to be a characteristic of this man or of this particular machine, but a combination of only this man with only this machine, and we would say that interaction was present. In the counting rate problem we expect any cause raising the reading for one specimen in an experiment to raise all readings similarly, and so we may confidently assume the interactions between experiments and specimens to be zero, i.e., $\eta_{ij} = 0$ for all i and j.

Returning to the table of means, we find the following linear relationships:

$$\sum_{i=1}^{4} \varphi_i = 0; \quad \sum_{j=1}^{4} \gamma_j = 0; \quad \sum_{i=1}^{4} \eta_{ij} = 0; \quad \sum_{j=1}^{4} \eta_{ij} = 0$$

Furthermore, instead of the original 16 means, we have introduced new parameters which will supply the results. By writing $\zeta_{ij} = \zeta_{..} + \varphi_i + \gamma_j + \eta_{ij}$ we can write the mean for the ith specimen and jth experiment as a constant, $\zeta_{..}$, plus an effect due to the ith specimen which is constant over all columns, φ_i, plus an effect due to the jth experiment which is constant over all rows, γ_j, plus the interaction between the ith specimen and jth experiment. Testing whether (1) the specimens are homogeneous, (2) the experiments are homogeneous, and (3) whether there is any interaction is equivalent to testing:

(1) $\varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = 0$;
(2) $\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0$;
(3) $\eta_{ij} = 0$

for all i and j.

6.4 TWO-WAY CLASSIFICATION—ONE OBSERVATION PER CELL AND NO INTERACTION ASSUMED

In order to make an analysis with only one observation per cell it is necessary to assume that the interaction is 0. The model is as follows:

$$X_{ij} = \zeta_{..} + \varphi_i + \gamma_j + \epsilon_{ij}$$

where

X_{ij} is the outcome of the experiment using the ith row effect and jth column effect, $i = 1, 2, \ldots, r$; $j = 1, 2, \ldots, s$;

$\zeta_{..}$ is a general mean;

φ_i is the effect of adding the ith row treatment; $\sum_{i=1}^{r} \varphi_i = 0$;

γ_j is the effect of adding the jth column treatment; $\sum_{j=1}^{s} \gamma_j = 0$;

ϵ_{ij} is the random effect, which is independently normally distributed with mean 0 and variance σ^2.

6.4.1 Tests for homogeneity. Complete the following analysis of variance table (Table 13.42):

Computational procedure for analysis of variance table is:

(1) Calculate row totals:

$R_1, R_2, \ldots, R_r$

(2) Calculate column totals:

$C_1, C_2, \ldots, C_s$

(3) Calculate over-all total:

$T = R_1 + R_2 + \ldots + R_r$

(4) Calculate crude total sum of squares:

$$\sum_{i=1}^{r} \sum_{j=1}^{s} X_{ij}^2 = X_{11}^2 + X_{12}^2 + \ldots + X_{rs}^2$$

(5) Calculate crude sum of squares between rows:

$$\sum_{i=1}^{r} \frac{R_i^2}{s} = (R_1^2 + R_2^2 + \ldots + R_r^2)/s$$

(6) Calculate crude sum of squares between columns:

$$\sum_{j=1}^{s} \frac{C_j^2}{r} = (C_1^2 + C_2^2 + \ldots + C_s^2)/r$$

(7) Calculate correction factor due to mean $= T^2/rs$.

From the above quantities compute

(8) $SS_4 = (6) - (7) = \sum_{j=1}^{s} \frac{C_j^2}{r} - T^2/rs$

(9) $SS_3 = (5) - (7) = \sum_{i=1}^{r} \frac{R_i^2}{s} - T^2/rs$

(10) $SS = (4) - (7) = \sum_{i=1}^{r} \sum_{j=1}^{s} X_{ij}^2 - T^2/rs$

(11) $SS_2 = (10) - (9) - (8) = SS - SS_3 - SS_4$

If

$$F_4 = \frac{SS_4/(s-1)}{SS_2/(r-1)(s-1)} = \frac{SS_4^*}{SS_2^*} \geq F_{\alpha;s-1;(r-1)(s-1)}$$

we reject the hypothesis that there is no column effect, i.e.,

$$\gamma_1 = \gamma_2 = \gamma_3 = \ldots = \gamma_s = 0$$

TABLE 13.42 ANALYSIS OF VARIANCE TABLE, TWO-WAY CLASSIFICATION, ONE OBSERVATION PER CELL

Source	Sum of squares	Degrees of freedom	Mean square	Average mean square	Test
Between columns	$SS_4 = r \sum_{j=1}^{s} (\bar{X}_{.j} - \bar{X}_{..})^2$	$s - 1$	$SS^*_4 = SS_4/(s-1)$	$\sigma^2 + \frac{r}{s-1} \sum_{j=1}^{s} \gamma_j^2$	$F_4 = SS^*_4/SS^*_2$
Between rows	$SS_3 = s \sum_{i=1}^{r} (\bar{X}_{i.} - \bar{X}_{..})^2$	$r - 1$	$SS^*_3 = SS_3/(r-1)$	$\sigma^2 + \frac{s}{r-1} \sum_{i=1}^{r} \varphi_i^2$	$F_3 = SS^*_3/SS^*_2$
Residue	$SS_2 = \sum_{i=1}^{r} \sum_{j=1}^{s} (X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..})^2$	$(r-1)(s-1)$	$SS^*_2 = SS_2/(r-1)(s-1)$	σ^2	
Total	$SS = \sum_{i=1}^{r} \sum_{j=1}^{s} (X_{ij} - \bar{X}_{..})^2$	$rs - 1$	$SS^* = SS/(rs-1)$	$\sigma^2 + \frac{r}{rs-1} \sum_{j=1}^{s} \gamma_j^2 + \frac{s}{rs-1} \sum_{i=1}^{r} \varphi_i^2$	

In this table, $\bar{X}_{.j} = \sum_{i=1}^{r} X_{ij}/r$; $\quad \bar{X}_{i.} = \sum_{j=1}^{s} X_{ij}/s$; $\quad \bar{X}_{..} = \sum_{i=1}^{r} \sum_{j=1}^{s} X_{ij}/rs$

where $F_{\alpha;s-1,(r-1)(s-1)}$ is the upper α percentage point of the F distribution given in Table 13.27.

If
$$F_3 = \frac{SS_3/(r-1)}{SS_2/(r-1)(s-1)} = \frac{SS_3^*}{SS_2^*} \geq F_{\alpha;r-1,(r-1)(s-1)}$$

we reject the hypothesis that there is no row effect, i.e.,

$$\varphi_1 = \varphi_2 = \varphi_3 = \ldots = \varphi_r = 0$$

where $F_{\alpha;r-1,(r-1)(s-1)}$ is the upper α percentage point of the F distribution given in Table 13.27.

6.4.2 Tests for comparison of mean effect. If the hypothesis that there is no row effects or no column effects, or both, is rejected, Tukey's method can again be applied to get confidence intervals on the difference between two row effects or two column effects. The probability is $1 - \alpha$ that the value $(\varphi_k - \varphi_l)$ for *all* such contrasts (for $k = 1, 2, \ldots, r$; $l = 1, 2, \ldots, r$) simultaneously satisfy

$$\bar{X}_{k.} - \bar{X}_{l.} - c \leq \varphi_k - \varphi_l \leq \bar{X}_{k.} - \bar{X}_{l.} + c$$

and the probability is $1 - \alpha$ that the values $(\gamma_m - \gamma_n)$ for *all* such contrasts (for $m = 1, 2, \ldots, s$; $n = 1, 2, \ldots, s$) simultaneously satisfy

$$\bar{X}_{.m} - \bar{X}_{.n} - c \leq \gamma_m - \gamma_n \leq \bar{X}_{.m} - \bar{X}_{.n} + c$$

Again two mean effects are judged significantly different when 0 is not included in the confidence interval.

The factor c for row effects and for column effects is obtained from the analysis of variance table and from Table 13.38 or Table 13.39 depending on the level of significance. Table 13.38 or 13.39 is entered with the indices degrees of freedom, and the number of row effects being studied (r) if row effects are of interest. The proper degrees of freedom are those corresponding to the degrees of freedom of the residual source in the analysis of variance table, i.e., $(r - 1)(s - 1)$. The factor c^* is read from the table, and

$$c \text{ (for rows)} = c^*\sqrt{SS_2^*/s}$$

Similarly, if column effects are of interest, the table is entered with indices degrees of freedom and the number of column effects being studied (s). The factor c^* is read from the table and

$$c \text{ (for columns)} = c^*\sqrt{SS_2^*/r}$$

6.4.3 Estimating the variability due to the sources. If there were no row effects and no column effects, the column headed "Average mean square" in the analysis of variance table would contain σ^2 for the row source entry and σ^2 for the column source entry. The residual entry is always σ^2. The entry for the residual source, SS_2^*, in the "Mean square" column estimates σ^2. The values in the "Mean square" column for row effects, SS_3^*, and column effects, SS_4^*, estimate the corresponding value in the "Average mean square" column. The value of SS^* is an estimate of the total variability of the process (corresponding to the "Average mean square" entry). Since

$[(r-1)/s](SS_3^* - SS_2^*)$ is an estimate of $\sum_{i=1}^{r} \varphi_i^2$, and $[(s-1)/r](SS_4^* - SS_2^*)$ is an estimate of $\sum_{j=1}^{s} \gamma_j^2$, the contribution of these main effects to the total variability of the process can be estimated.

In some investigations, concern with reducing the total variability around the general mean is paramount. In such a case, this kind of analysis can be of value in determining the relative sizes of various contributions to the variability. In many other experiments, differences around the general mean are more to be identified than reduced, and this kind of analysis is irrelevant.

Many experiments which can be handled as a two-way analysis of variance might alternatively be attacked as a simpler one-way analysis of variance. For example, in the experiment on radium counts, rows correspond to specimens (difference among which we wish to estimate) and columns to experiments, where each specimen is handled in each experiment; this is a two-way plan. Alternatively, we *could* simply take 16 readings in random order, with each specimen being measured four times. The analysis of this second plan is arithmetically easier but it would seem to be a less precise experiment. Using the data and information given in the "Average mean square" column we can estimate the increase in precision resulting from using the two-way plan. This is done in the following way.

Calculate $SS_2^* + [r/(rs-1)] \sum \gamma_j^2$. This is an estimate of what the residual mean square would be had the experiment been done as a one-way analysis of variance. Clearly, if $\sum \gamma_j^2$ is large this means that the residual mean square for the one-way plan would be inflated from the value obtained by using the two-way plan. The ratio

$$e = \frac{SS_2^* + [r/(rs-1)] \sum \gamma_j^2}{SS_2^*}$$

is called the efficiency of the two-way plan relative to the one-way plan. And we can say approximately that for the same precision as that given by n observations in the two-way plan, $e \times n$ would be needed for a one-way plan.

6.4.4 Example. Let us return to the example of the counting rates for different specimens of radium using different experiments. The completed analysis of variance table is obtained by following the computational procedure.

(1) $R_1, R_2, R_3, R_4 = 6.45, 11.33, 17.20, 17.74$

(2) $C_1, C_2, C_3, C_4 = 12.73, 14.16, 13.14, 12.69$

(3) $T = 6.45 + 11.33 + 17.20 + 17.74 = 52.72$

(4) $\sum_{i=1}^{4} \sum_{j=1}^{4} X_{ij}^2 = (1.46)^2 + (2.00)^2 + \ldots + (4.15)^2$
$= 195.6948$

(5) $\sum_{i=1}^{4} \frac{R_i^2}{4} = \frac{(6.45)^2 + (11.33)^2 + (17.20)^2 + (17.74)^2}{4}$
$= 195.1298$

(6) $\sum_{i=1}^{4} \frac{C_i^2}{4} = \frac{(12.73)^2 + (14.16)^2 + (13.14)^2 + (12.69)^2}{4}$

$= 174.06355$

(7) $T^2/16 = (52.72)^2/16 = 173.7124$

(8) $SS_4 = 174.06355 - 173.7124 = 0.3512$

(9) $SS_3 = 195.1298 - 173.7124 = 21.4174$

(10) $SS = 195.6948 - 173.7124 = 21.9824$

(11) $SS_2 = 21.9824 - 21.4174 - 0.3512 = 0.2138.$

TABLE 13.43 COMPLETED ANALYSIS OF VARIANCE TABLE FOR COUNTING RATE PROBLEM

Source	Sum of squares	Degrees of freedom	Mean square	Test
Between experiments	0.3512	3	0.1171	$F_4 = 4.93$
Between specimens	21.4174	3	7.1391	$F_3 = 300.5$
Residual	0.2138	9	0.0238	
Total	21.9824	15	1.4655	

$F_{.05;3,9} = 3.86$

Consequently, we conclude that the specimen effects differ significantly, and the experiment effects also differ significantly. Hence, determining the largest effects is in order.

For experiments and from Table 13.38 for $\alpha = 0.05$ and for $r = 4$, $s = 4$.

$$c^* = 4.42$$

so that

$$c = 4.42\sqrt{\frac{SS_2^*}{4}} = 0.3408$$

Making the comparison between the second and fourth experiment effect,

$$(3.54 - 3.17) - 0.34 \leq \gamma_2 - \gamma_4 \leq (3.54 - 3.17) + 0.34$$
$$0.03 \leq \gamma_2 - \gamma_4 \leq 0.71$$

It is evident that they differ significantly. Furthermore, the difference $\gamma_2 - \gamma_4$ can be said to lie between 0.03 and 0.71.

It is evident by inspection that the only other significant difference is between γ_2 and γ_1 Hence we can conclude that experiment 2 produced an effect on the counting rate which was significantly different from the others.

For specimens, c^* also equals 4.42, so that c is again 0.3408.

Making the comparison between the third and fourth specimen effects,

$$(4.44 - 4.30) - 0.34 \leq \varphi_4 - \varphi_3 \leq (4.44 - 4.30) + 0.34$$
$$-0.20 \leq \varphi_4 - \varphi_3 \leq 0.48$$

It appears that these two specimens do *not* differ. From inspection of the data, it is evident that these are the only two specimens that do not differ signifi-

cantly. The difference between specimen effect 4 and specimen effect 1 can be said to lie between 2.49 and 3.17, i.e.,

$$2.49 \leq \varphi_4 - \varphi_1 \leq 3.17$$

6.4.5 Estimates of variability. The estimate of

$$\sigma^2 + \frac{r}{s-1}\sum_{j=1}^{s}\gamma_j^2 = \sigma^2 + \frac{4}{3}\sum_{j=1}^{4}\gamma_j^2$$

is 0.1171. The estimate of σ^2 is 0.0238. Hence, the estimate of $\sum_{j=1}^{4}\gamma_j^2$ is

$$\tfrac{3}{4}(0.1171 - 0.0238) = 0.0699$$

Similarly, the estimate of

$$\sigma^2 + \frac{s}{r-1}\sum_{i=1}^{r}\varphi_i^2 = \sigma^2 + \frac{4}{3}\sum_{i=1}^{4}\varphi_i^2$$

is 7.1391. Hence the estimate of $\sum_{i=1}^{4}\varphi_i^2$ is

$$\tfrac{3}{4}(7.1391 - 0.0238) = 5.3364$$

We may now compute the value of

$$SS_2^* + \frac{r}{rs-1}\sum\gamma_j^2 = 0.0238 + \frac{4}{(4)(4)-1}(0.0699) = 0.0424$$

and the efficiency of the two-way plan used, relative to a one-way plan (where the 16 readings would not be taken in sets of four) is: 0.0424/0.0238 = 1.78, which means that about 16 × 1.78 = 29 observations taken in random order would be needed to give as precise results as those obtained by using the two-way plan.

6.5 TWO-WAY CLASSIFICATION—MORE THAN ONE OBSERVATION PER CELL—INTERACTION

The model is as follows:

$$X_{ijk} = \zeta_{..} + \varphi_i + \gamma_j + \eta_{ij} + \epsilon_{ijk}$$

where

X_{ijk} is the outcome of the kth experiment using the ith row effect and jth column effect, $i = 1, 2, \ldots, r$; $j = 1, 2, \ldots, s$; $k = 1, 2, \ldots, v$;

$\zeta_{..}$ is a general mean;

φ_i is the effect of adding the ith row treatment, $\sum_{i=1}^{r}\varphi_i = 0$;

γ_j is the effect of adding the jth column treatment, $\sum_{j=1}^{s}\gamma_j = 0$;

η_{ij} is the interaction of the ith row treatment with the jth column treatment, $\sum_{i=1}^{r}\eta_{ij} = 0, \sum_{j=1}^{s}\eta_{ij} = 0$;

ϵ_{ijk} is the random effect which is independently normally distributed with mean 0 and variance σ^2.

6.5.1 Tests for homogeneity. Complete Table 13.44. Computational procedure for analysis of variance table:

(1) Calculate row totals:

$R_1, R_2, \ldots, R_r$

(2) Calculate column totals:

$C_1, C_2, \ldots, C_s$

(3) Calculate within cell totals:

$w_{11}, w_{12}, \ldots, w_{rs}$

(4) Calculate over-all total:

$T = R_1 + R_2 + \ldots + R_r$

(5) Calculate crude sum of squares:

$$\sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{v} X_{ijk}^2 = X_{111}^2 + X_{112}^2 + \ldots + X_{rsv}^2$$

(6) Calculate crude sum of squares between columns:

$$\sum_{j=1}^{s} \frac{C_j^2}{rv} = \frac{(C_1^2 + C_2^2 + \ldots + C_s^2)}{rv}$$

(7) Calculate crude sum of squares between rows:

$$\sum_{i=1}^{r} \frac{R_i^2}{sv} = \frac{(R_1^2 + R_2^2 + \ldots + R_r^2)}{sv}$$

(8) Calculate crude sum of squares between cells:

$$\sum_{i=1}^{r} \sum_{j=1}^{s} \frac{w_{ij}^2}{v} = \frac{(w_{11}^2 + w_{12}^2 + \ldots + w_{rs}^2)}{v}$$

(9) Calculate correction factor due to mean T^2/rsv

From the above quantities compute:

(10) $SS_4 = (6) - (9) = \sum_{j=1}^{r} \frac{C_j^2}{rv} - \frac{T^2}{rsv}$

(11) $SS_3 = (7) - (9) = \sum_{i=1}^{r} \frac{R_i^2}{sv} - \frac{T^2}{rsv}$

(12) $SS_1 = (5) - (8)$

$$= \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{v} X_{ijk}^2 - \sum_{i=1}^{r} \sum_{j=1}^{s} w_{ij}^2/v$$

(13) $SS = (5) - (9)$

$$= \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{v} X_{ijk}^2 - \frac{T^2}{rsv}$$

TABLE 13.44 ANALYSIS OF VARIANCE TABLE—TWO-WAY CLASSIFICATION—INTERACTION

Source	Sum of squares	Degrees of freedom	Mean square	Average mean square	Test
Between columns	$SS_4 = rv \sum_{j=1}^{s} (\bar{X}_{.j.} - \bar{X}_{...})^2$	$s - 1$	$SS^*_4 = SS_4/(s - 1)$	$\sigma^2 + \frac{rv}{s-1} \sum_{j=1}^{s} \gamma_j^2$	$F_4 = SS^*_4/SS^*_1$
Between rows	$SS_3 = sv \sum_{i=1}^{r} (\bar{X}_{i..} - \bar{X}_{...})^2$	$r - 1$	$SS^*_3 = SS_3/(r - 1)$	$\sigma^2 + \frac{sv}{r-1} \sum_{i=1}^{r} \varphi_i^2$	$F_3 = SS^*_3/SS^*_1$
Interaction	$SS_2 = v \sum_{i=1}^{r} \sum_{j=1}^{s} (\bar{X}_{ij.} - \bar{X}_{i..} - \bar{X}_{.j.} + \bar{X}_{...})^2$	$(r - 1)(s - 1)$	$SS^*_2 = SS_2/(r - 1)(s - 1)$	$\sigma^2 + \frac{v}{(r-1)(s-1)} \sum_{i=1}^{r} \sum_{j=1}^{s} \eta_{ij}^2$	$F_2 = SS^*_2/SS^*_1$
Within cells	$SS_1 = \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{v} (X_{ijk} - \bar{X}_{ij.})^2$	$rs(v - 1)$	$SS^*_1 = SS_1/rs(v - 1)$	σ^2	
Total	$SS = \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{v} (X_{ijk} - \bar{X}_{...})^2$	$rsv - 1$	$SS^* = SS/(rsv - 1)$	$\sigma^2 + \frac{rv}{rsv-1} \sum_{j=1}^{s} \gamma_j^2 + \frac{sv}{rsv-1} \sum_{i=1}^{r} \varphi_i^2 + \frac{v}{rsv-1} \sum_{i=1}^{r} \sum_{j=1}^{s} \eta_{ij}^2$	

In this table •

$$\bar{X}_{.j.} = \sum_{i=1}^{r} \sum_{k=1}^{v} X_{ijk}/rv; \qquad \bar{X}_{i..} = \sum_{j=1}^{s} \sum_{k=1}^{v} X_{ijk}/sv$$

$$\bar{X}_{ij} = \sum_{k=1}^{v} X_{ijk}/v; \qquad \bar{X}_{...} = \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{v} X_{ijk}/rsv$$

(14) $SS_2 = (13) - (12) - (11) - (10)$

$$= SS - SS_1 - SS_3 - SS_4$$

If there is more than one observation per cell and it is assumed *before the experiment is performed* that the interaction is zero, the interaction and within cells sums of squares are combined into a new row, where $SS_1' = SS_1 + SS_2$.

Source	Sum of squares	Degrees of freedom	Mean square	Average mean square
Residual	$SS'_1 = SS_1 + SS_2$	$(r-1)(s-1) + rs(v-1) = rsv - r - s + 1$	$SS'^{*}_1 = SS'_1/(rsv - r - s + 1)$	σ^2

In all formulas, SS_1 and SS_1^* are replaced by SS_1' and $SS_1'^*$, respectively.

In making tests of significance, when interaction may be present, it is important to first test for interaction.

If $F_2 = SS_2^*/SS_1^* \geq F_{\alpha,(r-1)(s-1),rs(v-1)}$ we reject the hypothesis that there is no interaction present, i.e., that $\eta_{ij} = 0$ for all i, j, where $F_{\alpha,(r-1)(s-1),rs(v-1)}$ is the upper α percentage point of the F distribution given in Table 13.27.

If this hypothesis is rejected, the tests for significance of row effects and column effects are meaningless under the present formulation of the problem. For example, suppose there is interaction present between workmen and machines, and suppose that there are also significant machine effects. If a particular machine effect is positive, and interaction is present, there is no guarantee that this machine will produce more units consistently. Yet, this is what is implied by saying that this machine has a positive effect. Consequently, if interaction is present, tests for row effects and column effects are irrelevant.

If the hypothesis that there is no interaction is accepted, we reject the hypothesis that there are no column effects, i.e.,

$$\gamma_1 = \gamma_2 = \gamma_3 = \ldots = \gamma_s = 0$$

if $F_4 = SS_4^*/SS_1^* \geq F_{\alpha;s-1,rs(v-1)}$.

We reject the hypothesis that there are no row effects, i.e.,

$$\varphi_1 \quad \varphi_2 = \varphi_3 \qquad \varphi_r \quad 0$$

if $F_3 = SS_3^*/SS_1^* \geq F_{\alpha;r-1,rs(v-1)}$.

6.5.2 Tests for comparison of mean effects. If the interactions are not significant, the procedure for comparing row or column effects is exactly the same as for the two-way classification with one observation per cell except for the following changes.

The factor c for row effects and for column effects is obtained from the analysis of variance table and from Table 13.38 or Table 13.39, depending on the level of significance. Table 13.38 or 13.39 is entered with the indices degrees of freedom, and the number of row effects being studied (r) if row

effects are of interest. The proper degrees of freedom are those corresponding to the degrees of freedom of the within cell source in the analysis of variance table, i.e., $rs(v-1)$. The factor c^* is read from the table and

$$c \text{ (for rows)} = c^*\sqrt{SS_1^*/vs}$$

Similarly, if column effects are of interest, the table is entered with indices degrees of freedom, and the number of column effects being studied (s). The factor c^* is read from the table and

$$c \text{ (for columns)} = c^*\sqrt{SS_1^*/vr}$$

Of course, for finding confidence intervals, the calculated terms that are of interest are $\bar{X}_{i..}$ and $\bar{X}_{.j.}$.

6.5.3 **Estimating the variability due to the sources.** In many problems to which this experimental plan is applicable the main concern is with estimating the size of row effect differences, column effect differences, and magnitudes of interactions. However, if the investigation is principally concerned with estimating the relative sizes of contributions to the total variance around the general mean, these can be estimated.

The column of the analysis of variance table headed "Mean square" is an estimate of the corresponding entry in the column headed "Average mean square." Consequently, we can calculate estimates of $\sum_{i=1}^{r}\varphi_i^2$, $\sum_{j=1}^{s}\gamma_j^2$, and $\sum_{i=1}^{r}\sum_{j=1}^{s}\eta_{ij}^2$.

$$\text{estimate of } \sum_{j=1}^{s}\gamma_j^2 = (SS_4^* - SS_1^*)\,\frac{s-1}{rv}$$

$$\text{estimate of } \sum_{i=1}^{r}\varphi_i^2 = (SS_3^* - SS_1^*)\,\frac{r-1}{sv}$$

$$\text{estimate of } \sum_{i=1}^{r}\sum_{j=1}^{s}\eta_{ij}^2 = (SS_2^* - SS_1^*)\,\frac{(r-1)(s-1)}{v}$$

We cannot appropriately calculate the efficiency of this design to a one-way plan, since the two plans are not really comparable; the information on interactions cannot be obtained from the one-way plan.

6.5.4 **Example.** Youden* reports the following experiment to determine the effect of time of aging in the strength of cement. Two mixes of cement were prepared and 6 specimens were made from each mix. Three specimens from each mix were tested after three days and after seven days. Interaction cannot be ignored since it is quite possible that the two mixes might not differ after a short period of time, but would after a longer period. This is equivalent to saying that the effect of an additional period of time is different for the two mixes, i.e., interaction is present. The test specimens are 2-in. cubes that yielded under the indicated loads, which are in units of 10 lb.

* W. J. Youden, *Statistical Methods for Chemists* (New York. John Wiley & Sons, Inc., 1951), pp. 64-65.

TABLE 13.45 YIELD LOADS FOR CEMENT SPECIMENS

	3-day test	7-day test	$\bar{X}_i$
Mix 1	660 674 648	979 1038 1051	841.7
Mix 2	661 624 652	1070 1066 1053	854.3
$\bar{X}_j$	653.2	1042.8	

The following computations lead to the Analysis of Variance Table.

(1) $R_1, R_2 = 5050, 5126$

(2) $C_1, C_2 = 3919, 6257$

(3) $w_{11}, w_{21}, w_{12}, w_{22} = 1982, 1937, 3068, 3189$

(4) $T = 5050 + 5126 = 10{,}176$

(5) $$\sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{3} X_{ijk}^2 = (660)^2 + (674)^2 + \ldots + (1053)^2 = 9{,}091{,}732$$

(6) $$\sum_{j=1}^{2} \frac{C_j^2}{6} = \frac{(3919)^2 + (6257)^2}{6} = 9{,}084{,}768$$

(7) $$\sum_{i=1}^{2} \frac{R_i^2}{6} = \frac{(5050)^2 + (5126)^2}{6} = 8{,}629{,}729$$

(8) $$\sum_{i=1}^{2} \sum_{j=1}^{2} \frac{w_{ij}^2}{3} = \frac{(1982)^2 + (1937)^2 + (3068)^2 + (3189)^2}{3} = 9{,}087{,}546$$

(9) $$\frac{T^2}{12} = \frac{(10{,}176)^2}{12} = 8{,}629{,}248$$

(10) $SS_4 = 9{,}084{,}768 - 8{,}629{,}248 = 455{,}520$

(11) $SS_3 = 8{,}629{,}729 - 8{,}629{,}248 = 481$

(12) $SS_1 = 9{,}091{,}732 - 9{,}087{,}546 = 4{,}186$

(13) $SS = 9{,}091{,}732 - 8{,}629{,}248 = 462{,}484$

(14) $SS_2 = 462{,}484 - 4{,}186 - 481 - 455{,}520 = 2{,}297$

ANALYSIS OF VARIANCE TABLE FOR YIELD LOADS ON CEMENT SPECIMENS

Source	Sum of squares	Degrees of freedom	Mean square	Test
Between times	455,520	1	455,520	$F = 870.54$
Between mixes	481	1	481	$F = 0.919$
Interaction	2,297	1	2,297	$F = 4.39$
Within cells	4,186	8	523.25	
Total	462,484	11	42,044	

The F values in the table for interaction and mixes is well below the critical 5% value for 1 and 8 degrees of freedom, i.e., $F_{.05;1,8} = 5.32$. Hence it is concluded that the data do not give sufficient evidence of the presence of interaction or any mix effect. On the other hand, the F test for times is significant, so that it is concluded that there is an effect from the additional four days of aging. Furthermore, a comparison of the column means indicates that

$$\bar{X}_{.2} - \bar{X}_{.1} - c \leq \gamma_2 - \gamma_1 \leq \bar{X}_{.2} - \bar{X}_{.1} + c$$

or

$$\begin{aligned}(1042.8 - 653.2) - 30.4 = 359.2 &\leq \text{mean effect for 7 days} - \text{mean effect} \\ &\quad \text{for 3 days} \\ &\leq (1042.8 - 653.2) + 30.4 = 420.0\end{aligned}$$

where c is obtained from Table 13.38, using as indices: $s = 2$; degrees of freedom $= rs(v - 1) = 8$; $c^* = 3.26$; so that

$$c = 30.4$$

In this problem we are not interested in finding the contributions of the main effects to the total variability about the mean. However, for illustrative purposes, we calculate the estimates of the magnitude of the main effects and interactions.

estimate of time effects

$$\begin{aligned}\sum \gamma_j^2 &= (SS_4^* - SS_1^*)\,\frac{s-1}{rv} \\ &= (455{,}520 - 523.25)\,\frac{1}{6} = \frac{454{,}996.75}{6} = 75{,}832.79\end{aligned}$$

estimate of mix effects

$$\begin{aligned}\sum \varphi_i^2 &= (SS_3^* - SS_1^*)\,\frac{r-1}{sv} = (481 - 523.25)\,\frac{1}{6} \\ &= 0 \quad \text{since} \quad \sum \varphi_i^2 \geq 0\end{aligned}$$

estimate of interaction effects

$$\begin{aligned}\sum\sum \eta_{ij}^2 &= (SS_2^* - SS_1^*)\,\frac{1}{3} \\ &= \frac{(2297 - 523.25)}{3} = \frac{1773.75}{3} = 591.25\end{aligned}$$

6.6 THREE-WAY CLASSIFICATION

The reader is cautioned to read the section on two-way classification, since the present article is merely a simple extension. The model is as follows:

$$X_{ijkl} = \zeta_{...} + \varphi_i + \gamma_j + \lambda_k + \eta_{ij} + \psi_{ik} + \mu_{jk} + \rho_{ijk} + \epsilon_{ijkl}$$

where

X_{ijkl} is the outcome of the lth experiment using the ith treatment of factor A, the jth treatment of factor B, and the kth treatment of factor C;

TABLE 13.46 ANALYSIS OF VARIANCE TABLE.

Source	Sum of squares	Degrees of freedom
Between treatments of factor C	$SS_5 = rsv \sum_{k=1}^{t} (\bar X_{..k.} - \bar X_{....})^2$	$t - 1$
Between treatments of factor B	$SS_4 = rtv \sum_{j=1}^{s} (\bar X_{.j..} - \bar X_{....})^2$	$s - 1$
Between treatments of factor A	$SS_3 = stv \sum_{i=1}^{r} (\bar X_{i...} - \bar X_{....})^2$	$r - 1$
Interaction AB	$SS_2^{AB} = vt \sum_{i=1}^{r} \sum_{j=1}^{s} (\bar X_{ij..} - \bar X_{i...} - \bar X_{.j..} + \bar X_{....})^2$	$(r - 1)(s - 1)$
Interaction AC	$SS_2^{AC} = rs \sum_{i=1}^{r} \sum_{k=1}^{t} (\bar X_{i.k.} - \bar X_{i...} - \bar X_{..k.} + \bar X_{....})^2$	$(r - 1)(t - 1)$
Interaction BC	$SS_2^{BC} = vr \sum_{j=1}^{s} \sum_{k=1}^{t} (\bar X_{.jk.} - \bar X_{.j..} - \bar X_{..k.} + \bar X_{....})^2$	$(s - 1)(t - 1)$
Interaction ABC	$SS_2^{ABC} = v \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{t} (\bar X_{ijk.} - \bar X_{ij..} - \bar X_{i.k.} - \bar X_{.jk.} + \bar X_{i...} + \bar X_{.j..} + \bar X_{..k.} - \bar X_{....})^2$	$(r - 1)(s - 1)(t - 1)$
Within cells	$SS_1 = \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{t} \sum_{l=1}^{v} (X_{ijkl} - \bar X_{ijk.})^2$	$rst(v - 1)$
Total	$SS = \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{t} \sum_{l=1}^{v} (X_{ijkl} - \bar X_{....})^2$	$rstv - 1$

In this table

$$\bar X_{..k.} = \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{l=1}^{v} X_{ijkl}/rsv, \qquad \bar X_{.j..} = \sum_{i=1}^{r} \sum_{k=1}^{t} \sum_{l=1}^{v} X_{ijkl}/rtv$$

$$\bar X_{i...} = \sum_{j=1}^{s} \sum_{k=1}^{t} \sum_{l=1}^{v} X_{ijkl}/stv; \qquad \bar X_{ij..} = \sum_{k=1}^{t} \sum_{l=1}^{v} X_{ijkl}/tv$$

$$\bar X_{i.k.} = \sum_{j=1}^{s} \sum_{l=1}^{v} X_{ijkl}/sv; \qquad \bar X_{.jk.} = \sum_{i=1}^{r} \sum_{l=1}^{v} X_{ijkl}/rv$$

$$\bar X_{ijk.} = \sum_{l=1}^{v} X_{ijkl}/v; \qquad \bar X_{....} = \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{t} \sum_{l=1}^{v} X_{ijkl}/rstv$$

THREE-WAY CLASSIFICATION, INTERACTION

Mean square	Average mean square	Test
$SS_5^* = \dfrac{SS_5}{t-1}$	$\sigma^2 + \dfrac{rsv}{t-1}\sum_{k=1}^{t}\lambda_k^2$	$F = \dfrac{SS_5^*}{SS_1^*}$
$SS_4^* = \dfrac{SS_4}{s-1}$	$\sigma^2 + \dfrac{rtv}{s-1}\sum_{j=1}^{s}\gamma_j^2$	$F = \dfrac{SS_4^*}{SS_1^*}$
$SS_3^* = \dfrac{SS_3}{r-1}$	$\sigma^2 + \dfrac{stv}{r-1}\sum_{i=1}^{r}\varphi_i^2$	$F = \dfrac{SS_3^*}{SS_1^*}$
$SS_2^{AB^*} = \dfrac{SS_2^{AB}}{(r-1)(s-1)}$	$\sigma^2 + \dfrac{vt}{(r-1)(s-1)}\sum_{i=1}^{r}\sum_{j=1}^{s}\eta_{ij}^2$	$F = \dfrac{SS_2^{AB^*}}{SS_1^*}$
$SS_2^{AC^*} = \dfrac{SS_2^{AC}}{(r-1)(t-1)}$	$\sigma^2 = \dfrac{vs}{(r-1)(t-1)}\sum_{i=1}^{r}\sum_{k=1}^{t}\psi_{ik}^2$	$F = \dfrac{SS_2^{AC^*}}{SS_1^*}$
$SS_2^{BC^*} = \dfrac{SS_2^{BC}}{(s-1)(t-1)}$	$\sigma^2 + \dfrac{vr}{(s-1)(t-1)}\sum_{j=1}^{s}\sum_{k=1}^{t}\mu_{jk}^2$	$F = \dfrac{SS_2^{BC^*}}{SS_1^*}$
$SS^{ABC^*} = \dfrac{SS_2^{ABC}}{(r-1)(s-1)(t-1)}$	$\sigma^2 + \dfrac{v}{(r-1)(s-1)(t-1)}\sum_{i=1}^{r}\sum_{j=1}^{s}\sum_{k=1}^{t}\rho_{ijk}^2$	$F = \dfrac{SS_2^{ABC^*}}{SS_1^*}$
$SS_1^* = \dfrac{SS_1}{rst(v-1)}$	σ^2	
$SS^* = \dfrac{SS}{rstv-1}$	$\sigma^2 + \dfrac{rsv}{rstv-1}\sum_{k=1}^{t}\lambda_k^2 + \dfrac{rtv}{rstv-1}\sum_{j=1}^{s}\gamma_j^2 + \dfrac{stv}{rstv-1}\sum_{i=1}^{r}\varphi_i^2$ $+ \dfrac{vt}{rstv-1}\sum_{i=1}^{r}\sum_{j=1}^{s}\eta_{ij}^2 + \dfrac{vs}{rstv-1}\sum_{i=1}^{r}\sum_{k=1}^{t}\psi_{ik}^2$ $+ \dfrac{vr}{rstv-1}\sum_{j=1}^{s}\sum_{k=1}^{t}\mu_{jk}^2 + \dfrac{v}{rstv-1}\sum_{i=1}^{r}\sum_{j=1}^{s}\sum_{k=1}^{t}\rho_{ijk}^2$	

$i = 1, 2, \ldots, r; j = 1, 2, \ldots, s; k = 1, 2, \ldots, t; l = 1, 2, \ldots, v;$

$\zeta\ldots$ is a general mean;

φ_i is the effect of adding the ith treatment of factor A, $\sum_{i=1}^{r}\varphi_i = 0;$

γ_j is the effect of adding the jth treatment of factor B, $\sum_{i=1}^{s}\gamma_j = 0;$

λ_k is the effect of adding the kth treatment of factor C, $\sum_{k=1}^{t}\lambda_k = 0;$

η_{ij} is the interaction of the ith treatment of factor A with the jth treatment of factor B, $\sum_{i=1}^{r} \eta_{ij} = \sum_{j=1}^{s} \eta_{ij} = 0$;

ψ_{ik} is the interaction of the ith treatment of factor A with the kth treatment of factor C, $\sum_{i=1}^{r} \psi_{ik} = \sum_{k=1}^{t} \psi_{ik} = 0$;

μ_{jk} is the interaction of the jth treatment of factor B with the kth treatment of factor C, $\sum_{j=1}^{s} \mu_{jk} = \sum_{k=1}^{t} \mu_{jk} = 0$;

ρ_{ijk} is the interaction of the ith treatment of factor A, the jth treatment of factor B, and the kth treatment of factor C, $\sum_{i=1}^{r} \rho_{ijk} = \sum_{j=1}^{s} \rho_{ijk} = \sum_{k=1}^{t} \rho_{ijk} = 0$;

ϵ_{ijkl} is the random effect, which is independently normally distributed with mean 0 and variance σ^2.

6.6.1 Tests for homogeneity. Complete the analysis of variance table (Table 13.46).

Computational procedure for the Analysis of Variance Table. For simplicity let $r = 2$, $s = 4$, $t = 3$, $v = 2$, and the data will appear in a table such as Table 13.47.

TABLE 13.47 EXAMPLE OF DATA FOR THREE-WAY CLASSIFICATION

		B_1	B_2	B_3	B_4
A_1	C_1	X_{1111} X_{1112}	X_{1211} X_{1212}	X_{1311} X_{1312}	X_{1411} X_{1412}
	C_2	X_{1121} X_{1122}	X_{1221} X_{1222}	X_{1321} X_{1322}	X_{1421} X_{1422}
	C_3	X_{1131} X_{1132}	X_{1231} X_{1232}	X_{1331} X_{1432}	X_{1431} X_{1432}
A_2	C_1	X_{2111} X_{2112}	X_{2211} X_{2212}	X_{2311} X_{2312}	X_{2411} X_{2412}
	C_2	X_{2121} X_{2122}	X_{2221} X_{2222}	X_{2321} X_{2322}	X_{2421} X_{2422}
	C_3	X_{2131} X_{2132}	X_{2231} X_{2232}	X_{2331} X_{2332}	X_{2431} X_{2432}

Form Tables 13.48, 13.49, and 13.50.

For Table 13.48:

(1) Calculate total $= X_{1+++} + X_{2+++}$

$$= \sum_{i=1}^{2} \sum_{j=1}^{4} \sum_{k=1}^{3} \sum_{l=1}^{2} X_{ijkl}$$

(2) Calculate crude sum of squares and divide by the number of original individuals that have been summed to give the individuals in this table:

$$\sum_{i=1}^{2} \sum_{j=1}^{4} \frac{X_{ij++}^2}{6} = \frac{X_{11++}^2 + X_{12++}^2 + \ldots + X_{24++}^2}{6}$$

TABLE 13.48 TABLE FOR FACTORS A AND B

	B_1	B_2	B_3	B_4	Totals
A_1	X_{11++} = total of all X's whose first two subscripts are 1,1	X_{12++} = total of all X's whose first two subscripts are 1,2	X_{13++} = total of all X's whose first two subscripts are 1,3	X_{14++} = total of all X's whose first two subscripts are 1,4	X_{1+++}
A_2	X_{21++} = total of all X's whose first two subscripts are 2,1	X_{22++} = total of all X's whose first two subscripts are 2,2	X_{23++} = total of all X's whose first two subscripts are 2,3	X_{24++} = total of all X's whose first two subscripts are 2,4	X_{2+++}
Totals:	X_{+1++}	X_{+2++}	X_{+3++}	X_{+4++}	

TABLE 13.49 TABLE FOR FACTORS B AND C

	B_1	B_2	B_3	B_4	Totals
C_1	X_{+11+} = total of all X's whose second subscript is 1 and third is 1	X_{+21+} = total of all X's whose second subscript is 2 and third is 1	X_{+31+} = total of all X's whose second subscript is 3 and third is 1	X_{+41+} = total of all X's whose second subscript is 4 and third is 1	X_{++1+}
C_2	X_{+12+} = total of all X's whose second subscript is 1 and third is 2	X_{+22+} = total of all X's whose second subscript is 2 and third is 2	X_{+32+} = total of all X's whose second subscript is 3 and third is 2	X_{+42+} = total of all X's whose second subscript is 4 and third is 2	X_{++2+}
C_3	X_{+13+} = total of all X's whose second subscript is 1 and third is 3	X_{+23+} = total of all X's whose second subscript is 2 and third is 3	X_{+33+} = total of all X's whose second subscript is 3 and third is 3	X_{+43+} = total of all X's whose second subscript is 4 and third is 3	X_{++3+}
Totals:	X_{+1++}	X_{+2++}	X_{+3++}	X_{+4++}	

TABLE 13.50 TABLE FOR FACTORS A AND C

	C_1	C_2		Totals
A_1	X_{1+1+} = total of all X's whose first subscript is 1 and third is 1	X_{1+2+} = total of all X's whose first subscript is 1 and third is 2	X_{1+3+} = total of all X's whose first subscript is 1 and third is 3	X_{1+++}
A_2	X_{2+1+} = total of all X's whose first subscript is 2 and third is 1	X_{2+2+} = total of all X's whose first subscript is 2 and third is 2	X_{2+3+} = total of all X's whose first subscript is 2 and third is 3	X_{2+++}
Totals:	X_{++1+}	X_{++2+}	X_{++3+}	

(3) Calculate crude sum of squares between rows and divide by the number of original individuals that have been summed to give the row totals:

$$\sum_{i=1}^{2} \frac{X_{i+++}^2}{24} = \frac{X_{1+++}^2 + X_{2+++}^2}{24}$$

(4) Calculate crude sum of squares between columns and divide by number of original individuals that have been summed to give the column total:

$$\sum_{j=1}^{4} \frac{X_{+j++}^2}{12} = \frac{X_{+1++}^2 + X_{+2++}^2 + X_{+3++}^2 + X_{+4++}^2}{12}$$

(5) Calculate correction factor due to mean which is total squared divided by total number of observations:

$$\frac{(1)^2}{48} = \frac{(\sum\sum\sum\sum X_{ijkl})^2}{48}$$

From the above factors compute:

(6) (2) − (5)

(7) $SS_3 = (3) - (5) = \sum_{i=1}^{2} \frac{X_{i+++}^2}{24} - \frac{(\sum\sum\sum\sum X_{ijkl})^2}{48}$

(8) $SS_4 = (4) - (5) = \sum_{j=1}^{4} \frac{X_{+j++}^2}{12} - \frac{(\sum\sum\sum\sum X_{ijkl})^2}{48}$

(9) $SS_2^{AB} = (6) - (7) - (8)$

In a similar manner, using the other two tables, the following can be computed:

(10) SS_5

(11) SS_2^{BC}

(12) SS_2^{AC}

To get the remaining factors:

(13) Calculate within cell totals from original data:

$$w_{111}, w_{112}, \ldots, w_{423}$$

(14) Calculate crude sum of squares between cells and divide by number of observations per cell:

$$\sum_{i=1}^{2} \sum_{j=1}^{4} \sum_{k=1}^{3} \frac{w_{ijk}^2}{2} = \frac{w_{111}^2 + w_{112}^2 + \ldots + w_{243}^2}{2}$$

(15) Calculate crude sum of squares:

$$\sum_{i=1}^{2} \sum_{j=1}^{4} \sum_{k=1}^{3} \sum_{l=1}^{2} X_{ijkl}^2 = X_{1111}^2 + X_{1112}^2 + \ldots + X_{2432}^2$$

From the above quantities compute:

(16) $SS_1 = (15) - (14) = \sum\sum\sum\sum X_{ijkl}^2 - \frac{\sum\sum\sum w_{ijk}^2}{2}$

(17) $SS = (15) - (5) = \sum\sum\sum\sum X_{ijkl}^2 - \dfrac{(\sum\sum\sum\sum X_{ijkl})^2}{48}$

(18) $SS_2^{ABC} = SS - SS_5 - SS_4 - SS_3 - SS_2^{AB} - SS_2^{AC} - SS_2^{BC} - SS_1$
$= (17) - (10) - (8) - (7) - (9) - (11) - (12) - (16)$

In making tests of significance when interaction may be present, it is important to test first for interaction between ABC.

If $F_2^{ABC} = SS_2^{ABC*}/SS_1^* \geq F_{\alpha;(r-1)(s-1)(t-1),rst(v-1)}$ we reject the hypothesis that there is no interaction between ABC present, i.e., that $\rho_{ijk} = 0$ for all ijk.

If this hypothesis is rejected, the tests for significance of effects A, effects B, and effects C are again meaningless under the present formulation of the problem (see Art. 6.5.1 for a discussion).

If F_2^{ABC} is not rejected, we make tests for interaction between AB, BC, and AC.

If $F_2^{AB} = SS_2^{AB*}/SS_1^* \geq F_{\alpha;(r-1)(s-1),rst(v-1)}$ we reject the hypothesis that there is no interaction between AB present, i.e., that $\eta_{ij} = 0$ for all i, j.

If $F_2^{AC} = SS_2^{AC*}/SS_1^* \geq F_{\alpha;(r-1)(t-1),rst(v-1)}$ we reject the hypothesis that there is no interaction between AC present, i.e., that $\psi_{ik} = 0$ for all i, k.

If $F_2^{BC} = SS_2^{BC*}/SS_1^* \geq F_{\alpha;(s-1)(t-1),rst(v-1)}$ we reject the hypothesis that there is no interaction between BC present, i.e., that $\mu_{jk} = 0$ for all j, k.

The presence of interaction between any two effects eliminates the need for tests of significance for these effects, since such a test is meaningless under the present formulation.

If all four types of interaction may be present, it is necessary that there be more than one observation per cell to make the necessary tests. However, if it is assumed that the interaction between ABC is 0, i.e., $\rho_{ijk} = 0$ for all ijk, a test can be formulated when there is only one observation in each cell, i.e., $v = 1$. The sources "within cells" and "interaction ABC" are eliminated in the analysis of variance table. It is replaced by the source "residual."

Source	Sum of squares	Degrees of freedom	Mean square	Average mean square
Residual	$SS'_1 = \sum_{i=1}^{r}\sum_{j=1}^{s}\sum_{k=1}^{t} (\bar{X}_{ijk.} - \bar{X}_{ij..} - \bar{X}_{i.k.} - \bar{X}_{.jk.} + \bar{X}_{i...} + \bar{X}_{.j..} + \bar{X}_{..k.} - \bar{X}_{....})^2$	$(r-1)(s-1)(t-1)$	$SS'^*_1 = \dfrac{SS'_1}{(r-1)(s-1)(t-1)}$	σ^2

All the tests are then made with the new source residual ($SS_1'^*$). For ease of computation SS_1' is obtained by subtraction.

Returning to tests of significance, if the interaction terms are nonsignificant, the tests for effects A, B, and C are made in the usual manner.

6.6.2 Tests for comparison of mean effects. If the interactions are nonsignificant, the procedure for comparing effects for factor A, effects for factor B, and effects for factor C is exactly the same as that given for the two-way classification except for the following changes.

The value of c for factor A, for factor B, and for factor C is obtained from the analysis of variance table and from Table 13.38 or Table 13.39 depending on the level of significance. Table 13.38 or 13.39 is entered, using as indices the degrees of freedom, and the number of A effects being studied (r) if A effects are of interest. The proper degrees of freedom are those corresponding to the degrees of freedom of the within cells source in the analysis of variance table, i.e., $rst(v - 1)$. The factor c^* is read from the table, and

$$c \text{ (for } A \text{ effects)} = c^* \sqrt{SS_1^*/vst}$$

Similarly, if B effects are of interest, the table is entered with indices degrees of freedom and the number of B effects being studied (s). The factor c^* is read from the table, and

$$c \text{ (for } B \text{ effects)} = c^* \sqrt{SS_1^*/vrt}$$

If C effects are of interest, the table is entered with indices degrees of freedom and the number of C effects being studied (t). The factor c^* is read from the table, and

$$c \text{ (for } C \text{ effects)} = c^* \sqrt{SS_1^*/vrs}$$

Of course, in considering confidence intervals, the calculated terms that are of interest are $\bar{X}_{i\cdot\cdot\cdot}$, $\bar{X}_{\cdot j\cdot\cdot}$, and $\bar{X}_{\cdot\cdot k\cdot}$.

6.6.3 Estimating the variability due to the sources. Estimates of the entries in the "Average mean square" column are obtained from the "Mean square" column. Hence estimates of

$$\sum_{i=1}^{r} \varphi_i^2, \quad \sum_{j=1}^{s} \gamma_j^2, \quad \sum_{k=1}^{t} \lambda_k^2, \quad \sum_{i=1}^{r} \sum_{j=1}^{s} \eta_{ij}^2, \quad \sum_{i=1}^{r} \sum_{k=1}^{t} \psi_{ik}^2, \quad \sum_{j=1}^{r} \sum_{k=1}^{t} \mu_{jk}^2$$

and $\sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{t} \rho_{ijk}^2$ can be calculated.

$$\text{estimate of } \sum_{i=1}^{r} \varphi_i^2 = (SS_3^* - SS_1^*) \frac{r-1}{stv}$$

$$\text{estimate of } \sum_{j=1}^{s} \gamma_j^2 = (SS_4^* - SS_1^*) \frac{s-1}{rtv}$$

$$\text{estimate of } \sum_{k=1}^{t} \lambda_k^2 = (SS_5^* - SS_1^*) \frac{t-1}{rsv}$$

$$\text{estimate of } \sum_{i=1}^{r} \sum_{j=1}^{s} \eta_{ij}^2 = (SS_2^{AB*} - SS_1^*) \frac{(r-1)(s-1)}{tv}$$

$$\text{estimate of } \sum_{i=1}^{r} \sum_{k=1}^{t} \psi_{ik}^2 = (SS_2^{AC*} - SS_1^*) \frac{(r-1)(t-1)}{sv}$$

$$\text{estimate of } \sum_{j=1}^{s} \sum_{k=1}^{t} \mu_{jk}^2 = (SS_2^{BC*} - SS_1^*) \frac{(s-1)(t-1)}{rv}$$

$$\text{estimate of } \sum_{i=1}^{r} \sum_{j=1}^{s} \sum_{k=1}^{t} \rho_{ijk}^2 = (SS_2^{ABC*} - SS_1^*) \frac{(r-1)(s-1)(t-1)}{v}$$

6.6.4 Example. An electronic manufacturer was having difficulty with a particular type of tube, where the mutual conductance was running below the bogie value. Actually this tube is interchangeable in radio sets with an alternate. An experiment was performed to determine the effect of the exhaust variables, plate temperature, and filament lighting on the electrical characteristics of the tubes. Two levels of plate temperature and four levels of filament lighting current were used.

TRANSCONDUCTANCE

		Filament lighting conditions L_1	L_2	L_3	L_4
Plate temperature T_1	Tube	3774	4710	4176	4540
		4364	4180	4140	4530
		4374	4514	4398	3964
	Alt.	4138	4276	4228	4292
		4503	4168	4570	4386
		4352	4244	4280	4660
Plate temperature T_2	Tube	4216	3828	4122	4484
		4524	4170	4280	4332
		4136	4180	4226	4390
	Alt.	4074	4224	4108	4326
		4030	3922	4070	4312
		4350	4146	3940	4426

The analysis of variance table is completed by following the prescribed procedure.

TABLE FOR FACTORS: TEMPERATURE AND LIGHTING CONDITIONS

	L_1	L_2	L_3	L_4	X_{i+++}
T_1	25,505	26,092	25,792	26,378	103,767
T_2	25,330	24,470	24,746	26,270	100,816
X_{+j++}	50,835	50,562	50,538	52,648	

(1) $X_{1+++} + X_{2+++} = 103{,}767 + 100{,}816 = 204{,}583$

(2) $$\sum_{i=1}^{2} \sum_{j=1}^{4} \frac{X_{ij++}^2}{6} = \frac{(25{,}505)^2 + (26{,}092)^2 + \ldots + (26{,}270)^2}{6}$$

$$= 872{,}531{,}808$$

(3) $\sum_{i=1}^{2} \frac{X_{i+++}^2}{24} = \frac{(103,767)^2 + (100,816)^2}{24} = 872,144,006$

(4) $\sum_{j=1}^{4} \frac{X_{+j++}^2}{12} = \frac{(50,835)^2 + (50,562)^2 + (50,538)^2 + (52,648)^2}{12}$

$= 872,217,868$

(5) $\frac{(1)^2}{48} = \frac{(204,583)^2}{48} = 871,962,581$

(6) (2) $-$ (5) $= 872,531,808 - 871,962,581 = 569,227$

(7) $SS_3 = 872,144,006 - 871,962,581 = 181,425$

(8) $SS_4 = 872,217,868 - 871,962,581 = 255,287$

(9) $SS_2^{AB} = 569,227 - 255,287 - 181,425 = 132,515$

TABLE FOR FACTORS: TUBE AND LIGHTING CONDITIONS

	L_1	L_2	L_3	L_4	X_{++k+}
Tube	25,388	25,582	25,342	26,240	102,552
Alternate	25,447	24,980	25,796	26,408	102,031
X_{+j++}	50,835	50,562	50,538	52,648	

(1) $X_{++1+} + X_{++2+} = 102,552 + 102,031 = 204,583$

(2) $\sum_{k=1}^{2} \sum_{j=1}^{4} \frac{X_{+jk+}^2}{6} = \frac{(25,388)^2 + (25,582)^2 + \ldots + (26,408)^2}{6}$

$= 872,252,486$

(3) $\sum_{k=1}^{2} \frac{X_{++k+}^2}{24} = \frac{(102,552)^2 + (102,031)^2}{24} = 871,968,236$

(4) $\sum_{j=1}^{4} \frac{X_{+j++}^2}{12} = \frac{(50,835)^2 + (50,562)^2 + (50,538)^2 + (52,648)^2}{12}$

$= 872,217,868$

(5) $\frac{(1)^2}{48} = \frac{(204,853)^2}{48} = 871,962,581$

(6) (2) $-$ (5) $= 872,252,486 - 871,962,581 = 289,905$

(7) $SS_5 = 871,968,236 - 871,962,581 = 5655$★

(8) $SS_4 = 872,217,868 - 871,962,581 = 255,287$

(9) $SS_3^{BC} = 289,905 - 5655 - 255,287 = 28,963$†

★ This result is denoted by (10) in the computational procedure.
† This result is denoted by (11) in the computational procedure.

TABLE FOR FACTORS, TUBES, AND TEMPERATURES

	Tube	Alternate	X_{i+++}
T_1	51,664	52,103	103,767
T_2	50,888	49,928	100,816
X_{++k+}	102,552	102,031	

(1) $X_{1+++} + X_{2+++} = 103{,}767 + 100{,}816 = 204{,}583$

(2) $$\sum_{i=1}^{2}\sum_{k=1}^{2}\frac{X_{i+k+}^2}{12} = \frac{(51{,}664)^2 + (52{,}103)^2 + (50{,}888)^2 + (49{,}928)^2}{12} = 872{,}190{,}435$$

(3) $$\sum_{i=1}^{2}\frac{X_{i+++}^2}{24} = \frac{(103{,}767)^2 + (100{,}816)^2}{24} = 872{,}144{,}006$$

(4) $$\sum_{k=1}^{2}\frac{X_{++k+}^2}{24} = \frac{(102{,}552)^2 + (102{,}031)^2}{24} = 871{,}968{,}236$$

(5) $$\frac{(1)^2}{48} = \frac{(204{,}583)^2}{48} = 871{,}962{,}581$$

(6) $(2) - (5) = 872{,}190{,}435 - 871{,}962{,}581 = 227{,}854$

(7) $SS_3 = 872{,}144{,}006 - 871{,}962{,}581 = 181{,}425$

(8) $SS_5 = 871{,}968{,}236 - 871{,}962{,}581 = 5655$

(9) $SS_2^{AC} = 227{,}854 - 181{,}425 - 5655 = 40{,}774$*

(13) $w_{111}, w_{112}, \ldots, w_{242} = 12{,}512; 13{,}404; \ldots ; 13{,}064$

(14) $$\sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{k=1}^{2}\frac{w_{ijk}^2}{3} = \frac{(12{,}512)^2 + (13{,}404)^2 + \ldots + (13{,}064)^2}{3} = 872{,}772{,}468$$

(15) $$\sum_{i=1}^{2}\sum_{j=1}^{4}\sum_{k=1}^{2}\sum_{l=1}^{3} X_{ijkl}^2 = (3774)^2 + (4364)^2 + \ldots + (4426)^2 = 873{,}947{,}177$$

(16) $SS_1 = 873{,}947{,}177 - 872{,}772{,}468 = 1{,}179{,}709$

(17) $SS = 873{,}947{,}177 - 871{,}962{,}581 = 1{,}984{,}596$

(18) $$SS_2^{ABC} = 1{,}984{,}596 - 5{,}655 - 255{,}287 - 181{,}425 - 132{,}515 - 40{,}774 - 28{,}963 - 1{,}174{,}709 = 165{,}268$$

The analysis of variance table reveals that only plate conditions give significant results. For plate temperatures,

$$\bar{X}_{1\cdot\cdot\cdot} = 4323.6 \quad \text{and} \quad \bar{X}_{2\cdot\cdot\cdot} = 4200.7$$

From Table 13.38, for 32 degrees of freedom and $r = 2$, $c^* = 2.88$, so that $c = 112.8$. Hence,

* This result is denoted by (12) in the computational procedure.

ANALYSIS OF VARIANCE TABLE FOR ELECTRONIC TUBE EXPERIMENT

Source	Sum of squares	Degrees of freedom	Mean square	Average mean square	Test
Between tube or alternate	5,655	1	5,655		$F = 0.154 \leq F_{.05;1,32}$
Between plate temperatures	181,425	1	181,425		$F = 4.94 \geq F_{.05;1,32}$
Between lighting conditions	255,287	3	85,095.7		$F = 2.32 \leq F_{.05;3,32}$
Interaction lighting conditions and plate temperatures	132,515	3	44,171.7		$F = 1.20 \leq F_{.05;3,32}$
Interaction lighting conditions and tube or alternate	28,963	3	9,654.3		$F = 0.260 \leq F_{.05;3,32}$
Interaction tube or alternate and plate temperatures	40,774	1	40,774		$F = 1.11 \leq F_{.05;1,32}$
Interaction plate temperatures, lighting conditions and tube or alternate	165,268	3	55,089.3		$F = 1.50 \leq F_{.05;3,32}$
Within cells	1,174,709	32	36,710		
Total	1,984,596	47			

$$(4323.6 - 4200.7) - 112.8 = 10.1 \leq T_1 \text{ effect} - T_2 \text{ effect} \leq (4323.6 - 4200.7) + 112.8 = 235.7$$

Thus to increase the mutual conductance, the tubes can be manufactured under plate temperature T_1.

6.7 LATIN SQUARE

In a three-way classification with four levels for each factor, there must be $4^3 = 64$ observations taken in order to analyze the experiment. Furthermore, it may be impossible to obtain observations for all combinations of all levels of the factors. For example, suppose that in the counting rate problem discussed in Arts. 6.3 and 6.4.4 there was an additional factor, order, besides the factors, specimens and experiments, i.e., a short-time effect may exist. It is impossible to obtain observations for all combinations of all levels, since only one specimen can be measured first in the first experiment. (It must be remembered that experiments were actually long-time

differences.) The difficulty is met by setting up the procedure so that all factors appear at the same number of levels. This procedure is an arrangement of the levels into a Latin square, which is simply a square array of letters such that every letter appears once and only once in every row and column.

TABLE 13.51 LATIN SQUARE TABLE

		Column factor 1	2	3	4
Row factor	1	*A*	*C*	*B*	*D*
	2	*B*	*D*	*A*	*C*
	3	*D*	*A*	*C*	*B*
	4	*C*	*B*	*D*	*A*

We can identify the letters with the four specimens. The column factor is the experiment and the row factor is the order. Thus the third specimen (C) is used second during the fourth experiment. Note that only 16 observations are required compared with the 64 if the factorial design were used (if it could be used). This saving is at the expense of a loss in degrees of freedom for estimating σ^2. Furthermore, the analysis of such a Latin square design requires that there be no interactions present. In spite of these two drawbacks, the Latin square, when applicable, is of great importance from the point of view of industrial experimentation.

The general model is

$$X_{ij(k)} = \zeta_{...} + \varphi_i + \gamma_j + \lambda_{(k)} + \epsilon_{ij(k)}$$

where the subscript i refers to rows, j to columns, and k to letters in the square. The k is enclosed in parentheses to indicate that it is not independent of i and j. Then

$X_{ij(k)}$ is the outcome of the experiment using the ith row effect, jth column effect, and (k)th letter effect, $i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, n$; $k = 1, 2, \ldots, n$;

$\zeta_{...}$ is a general mean;

φ_i is the effect of adding the ith row treatment, $\sum_{i=1}^{n} \varphi_i = 0$;

γ_j is the effect of adding the jth column treatment, $\sum_{j=1}^{n} \gamma_j = 0$;

$\lambda_{(k)}$ is the effect of adding the (k)th letter treatment, $\sum_{(k)=1}^{n} \lambda_{(k)} = 0$;

$\epsilon_{ij(k)}$ is the random effect which is independently normally distributed with mean 0 and variance σ^2.

6.7.1 Tests for homogeneity. Compute the following analysis of variance table (Table 13.52). Computational procedure is as follows:

(1) Calculate row totals:

$R_1, R_2, \ldots, R_n$

(2) Calculate column totals:

$C_1, C_2, \ldots, C_n$

(3) Calculate letter totals:

$L_1, L_2, \ldots, L_n$

(4) Calculate over-all total:

$T = R_1 + R_2 + \ldots + R_n$

(5) Calculate crude sum of squares:

$$\sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij(k)}^2 = X_{11}^2 + X_{12}^2 + \ldots + X_{nn}^2$$

(6) Calculate crude sum of squares between rows:

$$\sum_{i=1}^{n} \frac{R_i^2}{n} = \frac{R_1^2 + R_2^2 + \ldots + R_n^2}{n}$$

(7) Calculate crude sum of squares between columns:

$$\sum_{j=1}^{n} \frac{C_j^2}{n} = \frac{C_1^2 + C_2^2 + \ldots + C_n^2}{n}$$

(8) Calculate crude sum of squares between letters:

$$\sum_{(k)=1}^{n} \frac{L_{(k)}^2}{n} = \frac{L_1^2 + L_2^2 + \ldots + L_n^2}{n}$$

(9) Calculate correction factor due to mean $= T^2/n^2$.

From the quantities above compute:

(10) $SS_5 = (8) - (9) = \sum_{(k)=1}^{n} \frac{L_{(k)}^2}{n} - \frac{T^2}{n^2}$

(11) $SS_4 = (7) - (9) = \sum_{j=1}^{n} \frac{C_j^2}{n} - \frac{T^2}{n^2}$

(12) $SS_3 = (6) - (9) = \sum_{i=1}^{n} \frac{R_i^2}{n} - \frac{T^2}{n^2}$

(13) $SS = (5) - (9) = \sum_{i=1}^{n} \sum_{j=1}^{n} X_{ij(k)}^2 - \frac{T^2}{n^2}$

(14) $SS_2 = (13) - (12) - (11) - (10) = SS - SS_3 - SS_4 - SS_5$

TABLE 13.52 ANALYSIS OF VARIANCE TABLE, LATIN SQUARE

Source	Sum of squares	Degrees of freedom	Mean square	Average mean square	Test
Between letters	$SS_5 = n\sum_{(k)=1}^{n}(\bar{X}_{(k)} - \bar{X}_{..})^2$	$n-1$	$SS_5^* = \frac{SS_5}{n-1}$	$\sigma^2 + \frac{n}{n-1}\sum_{(k)=1}^{n}\lambda_{(k)}^2$	$F_5 = \frac{SS_5^*}{SS_2^*}$
Between columns	$SS_4 = n\sum_{j=1}^{n}(\bar{X}_{.j} - \bar{X}_{..})^2$	$n-1$	$SS_4^* = \frac{SS_4}{n-1}$	$\sigma^2 + \frac{n}{n-1}\sum_{j=1}^{n}\gamma_j^2$	$F_4 = \frac{SS_4^*}{SS_2^*}$
Between rows	$SS_3 = n\sum_{i=1}^{n}(\bar{X}_{i.} - \bar{X}_{..})^2$	$n-1$	$SS_3^* = \frac{SS_3}{n-1}$	$\sigma^2 + \frac{n}{n-1}\sum_{i=1}^{n}\varphi_i^2$	$F_3 = \frac{SS_3^*}{SS_2^*}$
Residual	$SS_2 = \sum_{i=1}^{n}\sum_{j=1}^{n}(X_{ij(k)} - \bar{X}_{i.} - \bar{X}_{.j} - \bar{X}_{(k)} + 2\bar{X}_{..})^2$	$(n-1)(n-2)$	$SS_2^* = \frac{SS_2}{(n-1)(n-2)}$	σ^2	
Totals	$SS = \sum_{i=1}^{n}\sum_{j=1}^{n}(X_{ij(k)} - \bar{X}_{..})^2$	n^2-1	$SS^* = \frac{SS}{n^2-1}$	$\sigma^2 + \frac{n}{n^2-1}\left(\sum_{(k)=1}^{n}\lambda_{(k)}^2 + \sum_{j=1}^{n}\gamma_j^2 + \sum_{i=1}^{n}\varphi_i^2\right)$	

In this table $\bar{X}_{(k)}$ = average over-all observations with the kth letter;

$$\bar{X}_{.j} = \sum_{i=1}^{n} X_{ij(k)}/n; \quad \bar{X}_{i.} = \sum_{j=1}^{n} X_{ij(k)}/n; \quad \bar{X}_{..} = \sum_{i=1}^{n}\sum_{j=1}^{n} X_{ij(k)}/n^2.$$

If $F_5 = SS_5^*/SS_2^* \geq F_{\alpha;n-1,(n-1)(n-2)}$ we reject the hypothesis that there are no letter effects, i.e., that

$$\lambda_{(1)} = \lambda_{(2)} = \ldots = \lambda_{(n)} = 0$$

If $F_4 = SS_4^*/SS_2^* \geq F_{\alpha;n-1,(n-1)(n-2)}$ we reject the hypothesis that there are no column effects, i.e., that

$$\gamma_1 = \gamma_2 = \ldots = \gamma_n = 0$$

If $F_3 = SS_3^*/SS_2^* \geq F_{\alpha;n-1,(n-1)(n-2)}$ we reject the hypothesis that there are no row effects, i.e., that

$$\varphi_1 = \varphi_2 = \ldots = \varphi_n = 0$$

6.7.2 Tests for comparison of mean effects. The procedure for comparing letter effects, row effects, and column effects is exactly the same as for the two-way classification except for the following changes.

The factor c for all three effects is obtained from the analysis of variance table and from Table 13.38 or 13.39, depending on the level of significance. Table 13.38 or 13.39 is entered, using as indices the degrees of freedom, and the number of levels of each factor (n). The proper degrees of freedom are those corresponding to the degrees of freedom of the residual source in the analysis of variance table, i.e., $(n - 1)(n - 2)$.

The factor c^* is read from the table for all three effects, and c is obtained from $c = c^*\sqrt{SS_2^*/n}$. Of course, for finding confidence intervals, the calculated terms that are of interest are $\bar{X}_{i.}$, $\bar{X}_{.j}$, and $\bar{X}_{(k)}$.

6.7.3 Estimating the variability due to the sources. Estimates of the entries in the "Average mean square" column are obtained from the "Mean square" column. Hence estimates of $\sum_{i=1}^{n} \varphi_i^2$, $\sum_{j=1}^{n} \gamma_j^2$, and $\sum_{(k)=1}^{n} \lambda_{(k)}^2$ can be calculated.

$$\text{estimate of } \sum_{i=1}^{n} \varphi_i^2 = (SS_3^* - SS_2^*)\frac{n-1}{n}$$

$$\text{estimate of } \sum_{j=1}^{n} \gamma_j^2 = (SS_4^* - SS_2^*)\frac{n-1}{n}$$

$$\text{estimate of } \sum_{(k)=1}^{n} \lambda_{(k)}^2 = (SS_5^* - SS_2^*)\frac{n-1}{n}$$

Often an experiment which can be treated as a Latin square might alternatively be attacked as a two-way plan, neglecting either the row or column grouping. For example, the counting rate problem has already been presented where the specimens were measured in random order in each experiment. We might hope to increase the precision by requiring that each specimen be measured first in one experiment, second in another, third in another, and fourth in another. This experimental plan is a more complicated one to carry out, and it will be worth while to assess how much the precision is increased as a guide in deciding how future investigations of a similar sort should be conducted.

The efficiency is calculated as:

$$e = \frac{SS_2^* + \dfrac{1}{n-1}\sum_{i=1}^{n} \varphi_i^2}{SS_2^*}$$

when the row grouping is neglected and

$$e = \frac{SS_2^* + \dfrac{1}{n-1}\sum_{j=1}^{n} \gamma_j^2}{SS_2^*}$$

when the column grouping is neglected.

We can say approximately that for the same precision as that given by the n^2 observations in the Latin square, $e \times n^2$ would be needed for a two-way plan.

6.7.4 Example. Consider the problem of the net counting rates described at the beginning of the article, where the factor "order" has been included. The letters represent specimens. The data are:

TABLE 13.53 NET COUNTING RATES LESS 25.00

	Experiment number				
Order	1	2	3	4	Order average
1	$A_{1.46}$	$C_{4.61}$	$B_{2.82}$	$D_{4.15}$	3.26
2	$B_{2.58}$	$D_{4.52}$	$A_{1.48}$	$C_{4.13}$	3.18
3	$D_{4.54}$	$A_{2.00}$	$C_{4.31}$	$B_{2.90}$	3.44
4	$C_{4.15}$	$B_{3.03}$	$D_{4.53}$	$A_{1.51}$	3.30
Experiment average	3.18	3.54	3.28	3.17	
Specimen average	$A_{1.61}$	$B_{2.83}$	$C_{4.30}$	$D_{4.44}$	

The analysis of variance table is obtained by following the computational procedure.

(1) $R_1, R_2, R_3, R_4 = 13.04, 12.71, 13.75, 13.22$

(2) $C_1, C_2, C_3, C_4 = 12.73, 14.16, 13.14, 12.69$

(3) $L_{(1)}, L_{(2)}, L_{(3)}, L_{(4)} = 6.45, 11.33, 17.20, 17.74$

(4) $T = 13.04 + 12.71 + 13.75 + 13.22 = 52.72$

(5) $$\sum_{i=1}^{4}\sum_{j=1}^{4} X_{ij(k)}^2 = (1.46)^2 + (4.61)^2 + \ldots + (1.51)^2$$
$$= 195.6948$$

(6) $$\sum_{i=1}^{4} \frac{R_i^2}{4} = \frac{(13.04)^2 + (12.71)^2 + (13.75)^2 + (13.22)^2}{4} = 173.8542$$

(7) $$\sum_{j=1}^{n} \frac{C_j^2}{4} = \frac{(12.73)^2 + (14.16)^2 + (13.14)^2 + (12.69)^2}{4} = 174.06355$$

$$(8)\ \sum_{(k)=1}^{4} \frac{L_{(k)}^2}{4} = \frac{(6.45)^2 + (11.33)^2 + (17.20)^2 + (17.74)^2}{4} = 195.1298$$

$$(9)\ T^2/n^2 = \frac{(52.72)^2}{16} = 173.7124$$

$$(10)\ SS_5 = 195.1298 - 173.7124 = 21.4174$$

$$(11)\ SS_4 = 174.06355 - 173.7124 = 0.3512$$

$$(12)\ SS_3 = 173.8542 - 173.7124 = 0.1418$$

$$(13)\ SS = 195.6948 - 173.7124 = 21.9824$$

$$(14)\ SS_1 = 21.9824 - 21.4174 - 0.3512 - 0.1418 = 0.0720$$

ANALYSIS OF VARIANCE TABLE FOR LATIN SQUARE DESIGN OF THE COUNTING RATE EXPERIMENT

	Sum of squares	Degrees of freedom	Mean square	Average mean square	Test
Between letters (specimens)	21.4174	3	7.1391		$F = 594.9$
Between columns (experiments)	0.3512	3	0.11707		$F = 9.76$
Between rows (order)	0.1418	3	0.0473		$F = 3.94$
Residual	0.0720	6	0.0120		
Totals	21.9824	15	1.4655		

For a critical value $F_{.05;3,6} = 4.76$, we see that the data indicate that both the specimens and experiments reveal significant differences. To judge which specimens differ, we enter Table 13.38 with $n = 4$ and degrees of freedom $= 6$, and $c^* = 4.90$, so that

$$c = 4.90 \times \tfrac{1}{2}\sqrt{0.0120} = 0.2695$$

and we can make such statements as: specimen 1 differs from specimen 2, 3, and 4; specimen 2 also differs from specimen 3 and 4; and furthermore with a confidence level of 0.95 we can make such statements as

$$(4.44 - 1.61) - 0.27 = 2.56 \leq \text{mean effect of specimen 4} - \text{mean effect of specimen 1} \leq (4.44 - 1.61) + 0.27 = 3.10$$

Similarly experiment 2 differs from experiment 1 and from experiment 4. To estimate the magnitude of the main effects we find

for specimens, $\sum \lambda_{(k)}^2 = (7.1391 - 0.0120)\tfrac{3}{4} = 5.3453$

for experiments, $\sum \gamma_j^2 \quad (0.11707 - 0.0120)\tfrac{3}{4} = 0.08690$

for order, $\sum \varphi_i^2 \quad (0.0473 - 0.0120)\tfrac{3}{4} = 0.0265$

We can compute now the efficiency of the Latin square relative to the two-way plan for these data where order is ignored.

$$e = \frac{0.0120 + \frac{1}{4-1}(0.0265)}{0.0120} = 1.74$$

This indicates that we have increased our information per observation by more than half, by taking account of order (in addition to experiments) in the design.

In the earlier treatment of these data, using only a two-way analysis, the value of c for getting confidence intervals was 0.34; in the present analysis the value of c is 0.27, which exhibits tangibly the gain resulting from the use of the Latin square design.

6.8 COMPONENTS OF VARIANCE MODEL

Throughout this article we have treated the problem where each observation is composed of two components, namely, the unknown mean of the population from which the observation is drawn and which is common to all observations within a set, and the deviation from this mean. Depending on the number of factors involved, each set mean could be further subdivided, and tests made on the component parts.

For example, in a small laboratory four thermometers are used interchangeably to make all temperature measurements. A natural question to ask is whether these thermometers differ. The model can be described as an observation consisting of a mean value common to a particular thermometer, and a deviation from this mean. Observations on a thermometer at the same temperature differ only because of these random deviations. A difference in thermometers is equivalent to speaking of a difference in the thermometer means. The techniques described above handle such problems.

However, it is possible that the problem at hand does not fit this model. For example, suppose that there are hundreds of thermometers used interchangeably to make temperature measurements. To perform an experiment with all the thermometers is too costly, and a random sample of 4 thermometers is drawn to determine whether thermometers differ. Naturally, the experimental results will depend heavily on which thermometers are chosen. Yet inferences are to be made about all the thermometers in the laboratory. The measurement may be considered as consisting of the two random components: (1) the deviation of the thermometer measurement from the mean value of the particular thermometer used, and (2) the deviation of the thermometer mean from the over-all mean of all the thermometers in the laboratory.

We are interested in determining not whether these particular thermometers chosen at random differ, but whether all the thermometers in the laboratory, of which these particular four thermometers are samples, differ.

Another way of expressing this is to determine whether the deviation of the population means of the different thermometers from the over-all mean are zero, i.e., the thermometer variance is zero. This type of problem can be characterized in that each observation is regarded as the sum of three components, namely, an unknown constant, the mean, which is common to all observations, and two random components which give rise to the total variability; one component producing the variation within the sets of observations, and the other producing the variation between the sets of observations.

Although it is important to distinguish between the two models formally, the analysis of variance table, computations, and procedures for significance tests are identical in both cases, with the following exceptions: (1) The column in the analysis of variance table headed "Average mean square" is replaced by a column headed "Components of variance." For example, Table 13.42 for the two-way classification would have the following entry

Sources	Components of variance
Between rows:	$\sigma^2 + s\sigma^2_{(\text{rows})}$
Between columns:	$\sigma^2 + r\sigma^2_{(\text{columns})}$
Residual:	σ^2

The entries in the "Mean square" column are now estimates of the entries in the column headed "Components of variance," so that $\sigma^2_{(\text{rows})}$ and $\sigma^2_{(\text{columns})}$ can be estimated. (2) If the possibility of interactions are allowed in the model, the sum of squares for main effects are usually compared with the proper interaction sum of squares in tests of significance. For example, for the two-way classification, with interaction, the test for interaction is still $F_2 = SS_2^*/SS_1^*$. However, the test for column effects involves SS_4^*/SS_2^*, and the test for row effects involves SS_3^*/SS_2^*.

6.9 HARTLEY'S TEST FOR HOMOGENEITY OF VARIANCES

Since a primary assumption in the analysis of variance is that the within-group variability be constant for all groups, we may wish to test the hypothesis that $\sigma_1^2 = \sigma_2^2 = \ldots = \sigma_k^2$.

The following test, known as Hartley's $F_{\max}$. test, will be suitable for the purpose.

Reject the hypothesis that the variances are equal when

$$H = \frac{\text{largest } s_i^2}{\text{smallest } s_i^2} \geq H_\alpha$$

where

$$s_i^2 = \sum_{j=1}^{n} \frac{(X_{ij} - \bar{X}_i)^2}{n-1} = \sum_{j=1}^{n} \frac{X_{ij}^2}{n-1} - \frac{n\bar{X}_i^2}{n-1}$$

and n = number of observations within each group (assumed the same for each group). Values of H_α are found in Table 13.54 by entering with n and k (the number of variances being considered).

TABLE 13.54 UPPER PERCENTAGE POINTS OF THE RATIO $s^2_{max.}/s^2_{min.}$ IN A SET OF k MEAN SQUARES, EACH BASED ON n OBSERVATIONS (Normal variation assumed)*

(a) 5% points

n \ k	2	3	4	5	6	7	8	9	10	11	12
3	39.0	87.5	142	202	266	333	403	475	550	626	704
4	15.4	27.8	39.2	50.7	62.0	72.9	83.5	93.9	104	114	124
5	9.60	15.5	20.6	25.2	29.5	33.6	37.5	41.1	44.6	48.0	51.4
6	7.15	10.8	13.7	16.3	18.7	20.8	22.9	24.7	26.5	28.2	29.9
7	5.82	8.38	10.4	12.1	13.7	15.0	16.3	17.5	18.6	19.7	20.7
8	4.99	6.94	8.44	9.70	10.8	11.8	12.7	13.5	14.3	15.1	15.8
9	4.43	6.00	7.18	8.12	9.03	9.78	10.5	11.1	11.7	12.2	12.7
10	4.03	5.34	6.31	7.11	7.80	8.41	8.95	9.45	9.91	10.3	10.7
11	3.72	4.85	5.67	6.34	6.92	7.42	7.87	8.28	8.66	9.01	9.34
13	3.28	4.16	4.79	5.30	5.72	6.09	6.42	6.72	7.00	7.25	7.48
16	2.86	3.54	4.01	4.37	4.68	4.95	5.19	5.40	5.59	5.77	5.93
21	2.46	2.95	3.29	3.54	3.76	3.94	4.10	4.24	4.37	4.49	4.59
31	2.07	2.40	2.61	2.78	2.91	3.02	3.12	3.21	3.29	3.36	3.39
61	1.67	1.85	1.96	2.04	2.11	2.17	2.22	2.26	2.30	2.33	2.36
∞	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

(b) 1% points

n \ k	2	3	4	5	6	7	8	9	10	11	12
3	199	448	729	1036	1362	1705	2063	2432	2813	3204	3605
4	47.5	85	120	151	184	216	249	281	310	337	361
5	23.2	37	49	59	69	79	89	97	106	113	120
6	14.9	22	28	33	38	42	46	50	54	57	60
7	11.1	15.5	19.1	22	25	27	30	32	34	36	37
8	8.89	12.1	14.5	16.5	18.4	20	22	23	24	26	27
9	7.50	9.9	11.7	13.2	14.5	15.8	16.9	17.9	18.9	19.8	21
10	6.54	8.5	9.9	11.1	12.1	13.1	13.9	14.7	15.3	16.0	16.6
11	5.85	7.4	8.6	9.6	10.4	11.1	11.8	12.4	12.9	13.4	13.9
13	4.91	6.1	6.9	7.6	8.2	8.7	9.1	9.5	9.9	10.2	10.6
16	4.07	4.9	5.5	6.0	6.4	6.7	7.1	7.3	7.5	7.8	8.0
21	3.32	3.8	4.3	4.6	4.9	5.1	5.3	5.5	5.6	5.8	5.9
31	2.63	3.0	3.3	3.4	3.6	3.7	3.8	3.9	4.0	4.1	4.2
61	1.96	2.2	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.7	2.7
∞	1.00	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

* from H. A. David, "Upper 5 and 1 Points of the Maximum F-Ratio," *Biometrika*, Vol. 39, Parts and 4, December 1952, p. 424.

7. ANALYSIS OF ENUMERATION DATA—CHI-SQUARE TESTS

7.1 INTRODUCTION

The problems considered in Art. 4 dealt with the measurements on certain variables; there are many experiments in which we count the number of cases which fall into specified categories. For example, we may record the number of defective items produced by various machines, the number of errors made by several operators, the number of hits and misses made by several firing control devices, the number of accidents as a function of the shift.

We will assume that each sample observation must fall into one and only one of k categories; let $0_1, 0_2, \ldots, 0_k$ be the observed frequencies for each category. We are interested in testing hypotheses about the true relative frequencies.

Category	Observed frequency	Theoretical frequency
1	0_1	E_1
2	0_2	E_2
.	.	.
.	.	.
.	.	.
k	0_k	E_k

The test statistic is

$$\chi^2 = \sum_{i=1}^{k} \frac{(0_i - E_i)^2}{E_i}$$

which for large enough samples has an approximate χ^2 distribution with a number of degrees of freedom which depends on how the data are used in computing the E_i.* Several problems of this sort are described in the following articles.

7.2 THE HYPOTHESIS COMPLETELY SPECIFIES THE RELATIVE FREQUENCIES OF THE CATEGORIES

Consider $p_1, p_2, \ldots, p_k$, where p_i is the true relative frequency of the ith category. In this type of problem, the theoretical frequencies are calculated from the formula $E_i = Np_i$ and the χ^2 statistic has $k - 1$ degrees of freedom.

7.2.1 Example. The total number of defective units in a day's production was tabulated by shifts.

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* The following rules of thumb can be used to assess adequacy of sample size:

1. If χ^2 has from 2 to 15 degrees of freedom, all E_i should be at least 2.5.
2. If χ^2 is computed from a 2 × 2 table (which will be discussed below), all E_i should be at least 5; however, if all but one of them is at least 5, the remaining one may be as small as 1 with little distortion in significance level.

	Observed frequency	Theoretical frequency
Shift 1:	20	26.67
Shift 2:	36	26.67
Shift 3:	24	26.67

It is of interest to see whether the variation from shift is due to chance or whether there is a real difference in the occurrence of defectives. That is, we test the hypothesis that the true relative frequencies of defectives are the same on all shifts, i.e., $p_1 = p_2 = p_3 = \frac{1}{3}$. Our test statistic is

$$\chi^2 = \frac{(20 - 26.67)^2}{26.67} + \frac{(36 - 26.67)^2}{26.67} + \frac{(24 - 26.67)^2}{26.67}$$

$$= \frac{44.4889}{26.67} + \frac{87.0489}{26.67} + \frac{7.1289}{26.67}$$

$$= 1.6681 + 3.2639 + 0.26730 = 5.1993 < \chi^2_{.05:2}$$

Therefore we accept the hypothesis and conclude that the data do not indicate that the frequencies differ.

7.3 TEST OF INDEPENDENCE IN A TWO-WAY CLASSIFICATION

Often frequency data are tabulated according to two criteria, with a view toward testing whether the criteria are associated. Consider the following analysis of the 157 machine breakdowns during a given quarter.

NUMBER OF BREAKDOWNS

	Machine				
	A	B	C	D	Total per shift
Shift 1	10	6	12	13	41
Shift 2	10	12	19	21	62
Shift 3	13	10	13	18	54
Total per machine	33	28	44	52	157

We are interested in whether the same percentage of breakdowns occur on each machine during each shift or whether there is some difference due perhaps to untrained operators or other factors peculiar to a given shift.

If the number of breakdowns are independent of shifts and machines, the probability of a breakdown occurring in the first shift and in the first machine can be estimated as

$$p_{11} = \frac{41}{157} \times \frac{33}{157} = 0.05489$$

If there are 157 breakdowns, the expected number of breakdowns on this shift and machines is estimated as

$$E_{11} = 157 \times p_{11} = 8.6177$$

Similarly for the third shift and second machine

$$p_{32} = \frac{54}{157} \times \frac{28}{157} = 0.06134$$

$$E_{32} = p_{32} \times 157 = 9.6306$$

This is done for all categories, and

$$\chi^2 = \sum_{i=1}^{3} \sum_{j=1}^{4} \frac{(0_{ij} - E_{ij})^2}{E_{ij}}$$

$$= \frac{(10 - 8.6177)^2}{8.6177} + \frac{(6 - 7.3120)^2}{7.3120} + \dots + \frac{(18 - 17.885)^2}{17.885} = 2.02$$

This is to be compared with the χ^2 statistic given in Table 13.26 for $(3 - 1)(4 - 1) = 6$ degrees of freedom, i.e., $\chi^2_{.05,6} = 12.6$. Hence we accept the hypothesis and conclude that the data do not indicate different percentages of breakdowns on each machine during each shift. In general, for an r by s table, we have

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{s} \frac{(0_{ij} - E_{ij})^2}{E_{ij}}$$

which has an approximate χ^2 distribution with $(r - 1)(s - 1)$ degrees of freedom.

7.4 COMPUTING FORM FOR TEST OF INDEPENDENCE IN A 2 BY 2 TABLE

An important special case of the test of independence arises when both criteria of classification have two categories; the data may be represented in a 2 by 2 table. The data may be represented in the following way:

First Criteria

Second criteria	a	b	$a + b$
	c	d	$c + d$
	$a + c$	$b + d$	

In this case the chi-square statistic which has one degree of freedom may be written

$$\chi^2 = \frac{(ad - bc)^2(a + b + c + d)}{(a + b)(a + c)(b + d)(c + d)}$$

7.4.1 Example. From the following data, determine whether the same percentage of breakdowns occur on each machine using material from each supplier.

NUMBER OF MACHINE BREAKDOWNS

Machine	Supplier A	Supplier B	
I	4	9	13
II	15	3	18
	19	12	31

$$\chi^2 = \frac{(12 - 135)^2(31)}{(13)(19)(12)(18)} = 8.8 \geq \chi^2_{.05;1} = 3.84$$

Therefore, we reject the hypothesis that the percentage of breakdowns is the same for each machine using material from each supplier.

7.5 COMPARISON OF TWO PERCENTAGES

A problem which in many cases is equivalent to the test of independence in a 2 by 2 table is the problem of testing equality of two percentages. Suppose, following Wallis,* we have the following data on two fire control devices.

	Hits	Misses	
Old	3	197	200
New	4	196	200
			400

Suppose we want to test the hypothesis that the percentage of hits is the same and want to reject when the new is superior, i.e., has a larger percentage of hits. If we let P_E be the observed proportion for the new experimental method, P_S be the observed proportion for the standard, and N be the number of trials with each method, then

$$U = \frac{\sqrt{N}(P_E - P_S)}{\sqrt{(P_E + P_S)[1 - (P_E + P_S)/2]}}$$

has approximately the normal distribution, and we would reject when $U \geq K_\alpha$. For the above data $P_S = 0.015$, $P_E = 0.020$, and

$$U = \frac{\sqrt{200}(0.005)}{\sqrt{0.020 + 0.015(1 - 0.035/2)}} = 0.3795 < U_{.05} = 1.645$$

and we accept the hypothesis and conclude that the data does not reveal that the new device is better than the old one.

In terms of the notation of the last section,

$$U = \frac{\sqrt{a + b + c + d}\,(ad - bc)}{\sqrt{(a + b)(a + c)(b + d)(c + d)}}$$

If we are interested in rejecting whenever the proportions differ, we could reject when $|U| \geq K_{\alpha/2}$ or when $U^2 \geq K^2_{\alpha/2}$. This is exactly the same as analyzing the data by the method in the last article.

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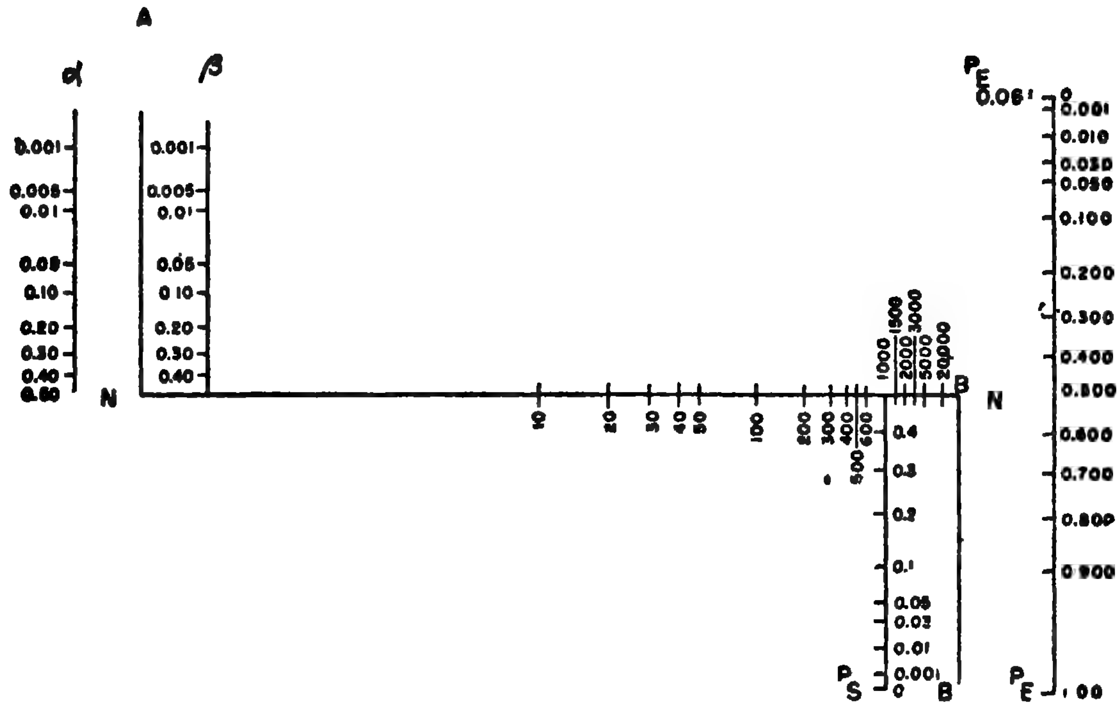
* Eisenhart, Hastay, and Wallis, *Techniques of Statistical Analysis*

A nomogram for determining sample size in problems of this sort is attached. It requires a guess at the true values of the percentage of hits with the standard and experimental method. Detailed instructions are on the nomogram (Fig. 13.46).

FIG. 13.46 NUMBER OF CASES REQUIRED FOR COMPARING TWO PERCENTAGES.



Reprinted by permission from C. Eisenhart, M. W. Hastay, and W. A. Wallis, *Techniques of Statistical Analysis* (New York: McGraw-Hill Book Company, Inc., 1947).

Directions:

1. Select values of α, β, P_S, and P_E (see explanation).
2. Locate the value of α on the scale marked "α".
3. Locate the value of β on the scale marked "β".
4. Locate the point at which a straight line from α to β cuts the scale marked "*A*".
5. Locate the value of P_S on the scale marked "P_S". If P_S exceeds 0.50 use $1 - P_S$ and make a corresponding change of P_E to $1 - P_E$.
6. Locate the value of P_E on the scale marked "P_E"
7. Locate the point at which a straight line from P_S to P_E cuts the scale marked "*B*".
8. Locate the point at which the scale marked "*N*" is cut by a straight line from the point on "*B*" to the point on "*A*". The "*N*" scale is calibrated so that the required sample size *N* is given opposite this point.

Explanation:

Call the two percentages being compared the "standard" and the "experimental."

α is defined as follows: We will conclude that the experimental method is better only if it shows in the experiment a superiority so great that the probability of this much superiority would be only α if the true long-run percentages were equal. In other words, α is the probability that we will erroneously judge the experimental method better when, in fact, the two methods are equally good.

β is the probability that we will fail to judge the experimental method better when, in fact, it is better. In other words, it is the probability that the experimental method, although actually better in the long run, will show a smaller superiority in the experiment than is required by the value of α for concluding that it is better.

P_S is an estimate of the true long-run probability for the standard method. This estimate can be based on prior experience, scientific judgment, etc.

P_E is an estimate of the true long-run probability for the experimental method. This estimate may be determined like that for P_S; or it may be the smallest figure above P_S for which it would be important to detect the superiority. For example, if $P_S = 0.10$, and if it would be important to detect any superiority of more than 50 per cent, we set $P_E = 0.15$.

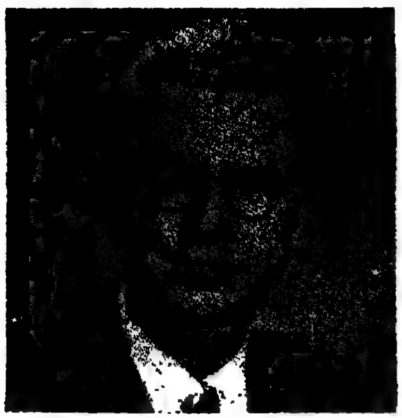
N is the number of trials with *each* method required in the experiment, as given by the formula

$$N = \frac{1}{2}\left(\frac{K_\alpha + K_\beta}{\text{arc sin}\sqrt{P_S} - \text{arc sin}\sqrt{P_E}}\right)^2$$

where K_ϵ is given by

$$\frac{1}{\sqrt{2\pi}}\int_{K_\epsilon}^{\infty} e^{-\frac{x^2}{2}}\,dx = \epsilon$$

and angles are measured in radians.



Wyatt H. Lewis, Manager of Quality Control at the Ontario, California, Plant of the General Electric Company, Small Appliance Division, has been given credit for initiating and operating the first successful statistical quality control program on the West Coast. The success of this program had an important influence on the establishment of the War Production Board's training program in statistical quality control during World War II. The exceptional growth of statistical quality control in American industry was greatly influenced by this training program.

For his work of outstanding merit in 1952, Mr. Lewis received the General Electric Company's Charles A. Coffin Award, the Company's highest honor to employees. Mr. Lewis has actively promoted quality control through his service in the American Society for Quality Control. He was secretary of the Los Angeles Section for several years, its chairman in 1950-51, and Western Regional Director and Director of the National organization. He has presented a number of papers at the national conventions and in many local sections. He has served on the Brumbaugh Award Committee and the Nominating Committee.

A native of Pasadena, Mr. Lewis received the B.S. degree in chemical engineering from the California Institute of Technology in 1933. He was employed as a Junior Chemical Engineer by the American Potash and Chemical Corporation at Trona from 1934 to 1937. He moved to the Sunkist Orange By-products plant at Ontario, as Pectin Plant Supervisor and Senior Chemical Engineer. At the outbreak of World War II, he sought a position where he could directly contribute to war production, and became associated with the Ontario Plant, General Electric Company. His first assignment was inspection planning, which led to later assignments in quality control.

SECTION 14

Inspection and Quality Control

Wyatt H. Lewis

1. FUNCTION AND RESPONSIBILITIES

1.1 INSPECTION

As long as man has made things, he has had some objective in mind. When his work is completed, he determines if he has accomplished his objective, and if the article serves its intended purpose. The latter act typifies the inspection act.

In modern manufacturing, the inspection function is *determining the acceptability of the manufactured article*. Generally, the acceptability is defined by the specification. (In some cases, acceptability is determined on a lot* basis rather than item by item. If the lot is defective, it is rejected for sorting and correction by the manufacturing group.)

1.2 QUALITY CONTROL

The quality control function includes the inspection function, but it goes much further. It is based on the concept that the making of unacceptable parts or products can be largely prevented. Statistical analysis of inspection data, commonly called statistical quality control, is valuable in accomplishing this objective. A lessening of scrap, rework, complaints, and so on, is a source of cost reduction. The economic aspects of quality should therefore be viewed as a major part of quality control. We may then say that the function of quality control is to *coordinate the quality control efforts in the manufacturing organization in such fashion as to carry on production at the most economical levels that will yield full customer satisfaction.* Various specific responsibilities essential to the execution of this principal function by the person responsible for quality control are listed below. (Many of these responsibilities will of necessity have to be delegated to various individuals within the quality control organization, depending upon the size of the operation.)

1. Recommend and establish quality control objectives, plans, and procedures.

2. Recommend and establish organization structure; define the function, responsibilities, authority, and accountability for each position.

3. Select and train personnel.

4. Supervise, provide leadership, and build individual and team morale in the unit.

5. Control unit operations by cooperating in establishing performance

* A lot is a group of parts or specimens presented for inspection at any one time.

standards, appraising performance against standards, and taking corrective action.

6. Assure adherence to established policies.

7. Review new designs for adequacy from the quality standpoint and approve where appropriate.

8. Establish inspection and test specifications and procedures to insure maintenance of quality.

9. Cooperate with purchasing section to establish vendor-consumer relationship that will insure purchased materials that meet specifications.

a. Provide rating sheet of vendors with respect to quality.

b. Promote certification of materials by vendors with respect to quality.

10. Provide the manufacturing group with statistical quality control charts and other devices for control of manufacturing processes.

11. Analyze inspection data to provide process control.

12. Conduct quality appraisals of final product to assure maintenance of product quality standards.

13. Conduct life tests on final product.

14. Gather and analyze complaint data from the field to measure degree of customer satisfaction.

15. Design experiments for engineering section to obtain maximum information with minimum expense.

16. Educate all groups in methods of accomplishing quality production.

17. Effect quality-mindedness at all levels in all sections.

18. Establish quality specification and sampling inspection plans for purchased and piece parts.

19. Review and approve, where appropriate, all deviations from specification.

20. Review and approve, where appropriate, part tools, dies, and molds, and recommend improvements or changes.

21. Conduct packaging tests to insure that the final product will arrive in the customer's hands in a satisfactory condition.

22. Observe all pilot runs and analyze results to serve as basis for making necessary quality improvements.

23. Where quality difficulties occur in the factory, recommend needed changes and improvements in design, methods, or tooling to respective persons in charge of these functions. Follow up to insure approved changes are made promptly.

24. Obtain necessary data by means of chemical and physical tests to insure proper control of material properties for both purchased and processed items.

25. Determine the assignable cause when parts or processes are "out of control."

26.* Procure and maintain test and inspection equipment to meet plant production requirements.

27.* Prepare test and inspection reports required by management.

2. ORGANIZATION

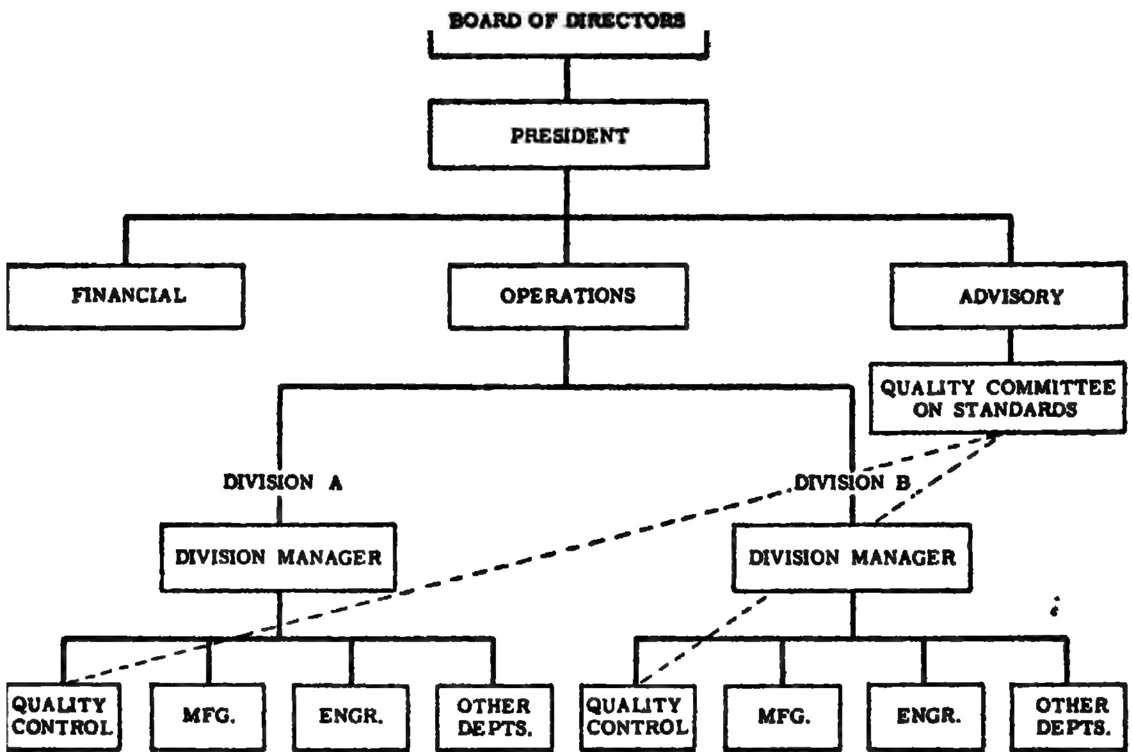
2.1 PURPOSE OF ORGANIZING

The purpose of organizing is to establish a relationship between the numerous industrial functions so that they will aid one another in reaching the common goal, eliminating friction and cross purposes. Organizing establishes lines of authority and responsibility. Where should the inspection and quality control functions fit into the organization to help other functions accomplish these purposes?

2.2 LOCATION IN THE ORGANIZATION: LARGE CORPORATION

In a large organization that manufactures a diversity of products at several different locations, the entire quality activity may be the sole responsibility of one of the vice-presidents. It may also be one of the responsibili-

* In an organization where the inspection function is separate from the quality control function, these responsibilities are usually assigned to the chief inspector.



From John G. Rutherford, *Quality Control in Industry* (New York: Pitman Publishing Corporation, 1948).

FIG. 14.1 ORGANIZATION CHART—LARGE CORPORATION.

ties of the vice-president in charge of engineering and manufacturing activities. At this level, only broad policy with regard to the quality function is established. These policies are sometimes established by an advisory staff to the president of the company. This general type of organization is illustrated in Fig. 14.1.

2.3 LOCATION IN THE ORGANIZATION: SMALLER ENTERPRISE OR OPERATING GROUP

Even in a large corporation, there are individual manufacturing groups or divisions that are usually headed by a manager. Within such an organization, there are several possible locations for inspection and quality control. In some cases, inspection is made a distinct section apart from quality control (see Art. 2.5). Often the two are combined in a single unit.

Where quality is important, the quality function should report either directly to the general manager (works manager) or to the manager of engineering. It is considered poor policy to have the quality function report to the plant superintendent or to the position responsible for manufacturing. The individual responsible for meeting production schedules is too likely to have his judgment on quality matters biased by the pressures for low-cost production under which he constantly operates.

Figure 14.2 shows the position of the quality control section in the organization of the individual plants of a large corporation or in the organization of the smaller manufacturing enterprise.

2.4 SEPARATION OF QUALITY CONTROL AND INSPECTION IN THE ORGANIZATION

In Figs. 14.1 and 14.2 it was assumed that the inspection unit

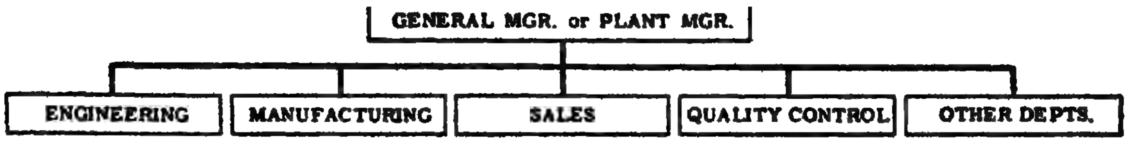


FIG. **14.2** ORGANIZATION CHART—PLANT LEVEL, QUALITY CONTROL A DEPARTMENT.

was a part of the quality control department or section. (In some organizations, the major designation is "inspection department" and the statistical quality control group is a part of the inspection department.) Not infrequently, quality control and inspection are completely separated. Such an arrangement overcomes the danger that the chief inspector will become so busy with the day-to-day operation of the inspection department that "he doesn't have the time to develop the use of modern quality control techniques." If a quality control engineer can quietly go aside and do some inspection planning and analysis of inspection results for the chief inspector and the factory organization, there is a much better chance of obtaining the full benefits of a quality control program. Obviously there must be close co-operation between these two sections of the organization.

Another advantage of having the quality control section separate is that it avoids any bias as far as the inspection section is concerned. The quality control section should be just as free to criticize inspection as it is to criticize design, vendors, tooling, or any other phase of the business that affects quality.

Figure 14.3 shows an organization in which the inspection section and the quality control section are separated. Of course, several other arrangements are possible.

2.5 USE OF COMMITTEES IN THE QUALITY ORGANIZATION

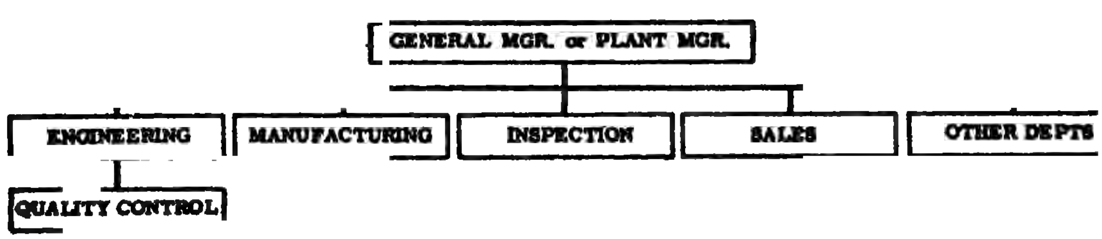
"Quality is Everybody's Job" is a quality campaign slogan with important meaning. Although the quality function is a staff or advisory function, it must extend into every line of the organization. Various committees provide an organization mechanism that accomplishes this purpose. Committees make the "in-line" parts of the organization part of the quality team. They provide a common ground on which various parts of the organization can cooperate on quality matters.

Figure 14.4 shows the make-up of some typical committees that cover various phases of the quality function.

2.6 THE QUALITY ORGANIZATION AND THE MANUFACTURING FOREMAN

The first responsibility for quality and its attainment should rest with the manufacturing foreman. Any organization for quality should strengthen the foreman in shouldering

FIG. **14.3** ORGANIZATION CHART—PLANT LEVEL, INSPECTION A DEPARTMENT, Q.C. UNDER ENGINEERING.



Standards Committe: Sets visual standards on final product General Manager Manager of Engineering Chief Inspector Manufacturing Superintendent Manager of Quality Control	**Salvage Committee or Materials Review: Reviews rejected material to decide on disposition, i.e., accept on deviation, rework, scrap.** Chief Inspector Manager of Quality Control Manager of Engineering Customer's Representative (necessary where work is performed for a government agency)	**Scrap and Rework Committee: Decides on corrective action to reduce scrap and rework costs.** Manager of Quality Control Manufacturing Superintendent All General Foremen
Quality Control Coordinating Committee: Coordinates all parts of the organization in obtaining corrective action on out-of-control processes. (Sometimes called the Action Committee.) General Manager (Coördination) Manager of Quality Control (Presentation of Data) Manager of Engineering (Product Design) Manufacturing Superintendent (Men and Machines) Manager of Methods Engineering (Methods & Processes) Chief Inspector (Inspection)	Customer Complaint Committee. Reviews field Complaints and decides on corrective action. General Manager Manager of Quality Control Chief Inspector Manager of Engineering General Foreman of Assembly Product Service Representative	New Product Committee General Manager Manager of Engineering Design Engineers Manager of Methods Engineering Manager of Quality Control

FIG. **14.4** COMMITTEES THAT SERVE THE QUALITY CONTROL FUNCTION.

this responsibility. Both inspection and quality control are service organizations that are provided to aid the foreman in obtaining quality and in reducing costs.

3. PERSONNEL

3.1 JOB SPECIFICATIONS: INSPECTION DEPARTMENT

A job specification should outline the following for each position:

1. Duties.
2. Educational requirements.
3. Special training.
4. Experience requirements.
5. Personal characteristics.

The usual job classifications in the inspection section are:

1. Chief inspector.
2. Inspection foreman.
3. Precision inspector.
4. Receiving inspector.
5. Patrol, roving, or floor inspector.
6. Bench or crib inspector.
7. Visual inspector.

3.2 JOB SPECIFICATIONS: QUALITY CONTROL

The usual job classifications in the quality control section are:

1. Manager of quality control.
2. Quality control engineer.*
3. Factory contact engineer.
4. Chemical and metallurgical engineer.
5. Laboratory assistants.

3.3 LIMITED PERSONNEL FOR STARTING A QUALITY CONTROL PROGRAM FOR THE SMALL PLANT

Usually the inspection department is an established and going part of the organization. The problem is how to

* Space does not permit a complete job specification for each job classification. J. M. Juran has given a complete specification for quality control engineer in his *Quality Control Handbook* (New York: McGraw-Hill Book Company, Inc., 1951), p. 171.

organize to obtain benefits from modern quality control techniques. This is usually done by choosing an engineer with the personal qualifications and training of a quality control engineer (see Art. 3.2) or by giving an engineer special training in statistical quality control (see Art. 3.4).

It is usually advisable to start on a small scale, analyzing existing inspection and cost data to determine those operations where quality control would offer the greatest benefit. If a few of these "bad spots" are cured, with the attendant saving in cost, management and the entire manufacturing organization will be eager to expand the quality control program. It is good advice to build slowly but well.

3.4 TRAINING PROGRAMS

Various persons in the organization must be trained in certain fundamentals of statistical quality control if the success of a quality control program is to be insured. This is best accomplished by in-plant training courses conducted by a qualified person within the organization (i.e., manager of quality control, quality control engineer) or by a qualified person outside the organization, such as a quality control consultant or a college instructor. Such in-plant courses are usually scheduled for as little as three hours of instruction or as much as ten or 20.

A number of educational institutions offer night-school classes in quality control subjects. Intensive courses are offered at frequent intervals by several universities throughout the United States. Information on such courses can be obtained from the American Society for Quality Control.* Announcements are made in the Society's publication *Industrial Quality Control*. These courses are best suited to the engineer or chief inspector, since they involve more time and effort than the average factory inspector would be willing or would need to spend. Statistics and statistical quality control are generally included in college and university curricula in industrial engineering and industrial management, and often are available as elective courses for other engineering and business students.

C. R. Scott, Jr., gives four levels of training and the subject matter for each in Juran's *Quality Control Handbook*, pp. 173, 174. The four levels are:

1. Top Management.
2. Shop Supervisors.
3. The Workmen.
4. The Quality Control Engineer.

In general, the following subjects are covered, with certain adaptations to fit the various levels:

- Variations
- Frequency Distribution
  - Average
  - Dispersion (Spread)
- Control Charts
  - for Variables
  - for Attributes
- Sampling Plans

Care must be taken with factory personnel not to overemphasize statistical theory. A knowledge of theory is not necessary for understanding broad principles or for carrying out control chart and sampling procedures.

Courses in advanced statistical techniques are offered by some educational institutions, usually in the form of intensive eight-day courses. Subject matter includes:

- Tests for significance.
- Analysis of variance.
- Multiple correlation.
- Design of experiments.
- Various other statistical tests and quality control techniques.

Reference should be made to the bibliography of this Section for suitable textbooks on quality control.

* American Society for Quality Control, Room 563, 50 Church Street, New York, N. Y.

3.5 SELECTION OF INSPECTORS

Selection should be made with job specifications in mind (see Art. 3.2). Integrity and judgment are two important characteristics, and good eyesight and visual perception are of great importance. Certain tests have been developed to measure visual characteristics. Two of these are the Ortho-Rater* and the Drake Tests.†

3.6 COMPENSATION FOR INSPECTORS

In industries that use incentive pay for manufacturing operators, a problem often arises when the operator receives a much higher rate of pay than the inspector who evaluates the operator's work. This situation, in turn, makes it difficult to attract persons of high calibre to inspection jobs. Some companies are meeting this problem by introducing incentive plans for inspectors. Incentive plans for inspectors, and the various elements involved, have been thoroughly covered by C. R. Scott, Jr., in Juran's *Quality Control Handbook*, p. 109, and by Juran in an earlier publication.‡

4. SPECIFICATIONS

4.1 PURPOSE OF SPECIFICATIONS

Except where someone is making something for his own use, there are at least two parties involved in the production process: the manufacturer and the consumer. The specification serves both parties. It *defines* in advance what the manufacturer expects to make. It *defines* what the consumer can expect to get. The specification serves as an *agreement* between manufacturer and consumer on the nature or characteristics of the product.

4.2 RESPONSIBILITY FOR SPECIFICATIONS

In our complex industrial organization many parties may contribute to the making of a specification, but it is advisable to have one part of the organization responsible for issuing and revising the specifications. Usually this is the product engineering or design engineering unit.

A convenient way for making sure that different parts of the organization have a voice in formulating the specification is to set up a standards committee (see Fig. 14.4). The action taken by the committee is recorded in the form of minutes and can be used by the product engineering unit as authorization to issue or revise the official specification.

When the specification has been agreed upon by all parties involved and has been officially issued, it becomes the "law" of the industrial community. It must be adhered to if chaos and confusion are to be prevented. It is up to the inspection department to see that the specification is enforced. If for any reason it becomes necessary to deviate from the specification, the product engineering unit should either revise the specification, if appropriate, or authorize a temporary deviation by means of an alteration notice (see Art. 4.8). There must be only one "law." Serious consequences may result if the shop decides to follow its own set of rules instead of the specification.

4.3 TYPES OF SPECIFICATIONS

Thus far in this section, when we have used the term "specification" we have been referring to the product specification. This is usually what is understood in industrial usage. We must,

* The Ortho-Rater is an optical device for measuring visual characteristics. Further information can be secured from Bausch and Lomb Optical Co., Rochester 2, New York.

† Drake Visual Perception Tests A and B are available from Mr. Charles A. Drake, 130 Garkey Street, Santa Cruz, California.

‡ *Management of Inspection and Quality Control* (New York: Harper and Brothers, 1945), 172.

however, not lose sight of the fact that there are other types of specifications used in industry. For example, we have:

1. Product specification, which defines nature or characteristic of product.

2. Manufacturing specification, which defines the process by which the product is to be made.

3. Test specification, which defines the manner in which the product is to be tested.

4. Packaging specification, which defines how the product is to be packed for safe transit to the consumer.

5. Acceptance specification, which defines criteria used for acceptance of the product, such as sampling procedures.

Confusion is avoided and revisions are more easily handled when these different types are brought together to form one all-inclusive specification.

4.4 DRAWING UP THE SPECIFICATION

The written specification may refer to blueprints, samples, color chips, roughness specimens, and other media by which quality characteristics can be expressed and defined.

Specification-writing is a subject in its own right. Space here does not permit an exhaustive treatment of the subject.* Obviously the specification should leave nothing for free interpretation. On the other hand, only enough detail should be employed to define the required characteristics.

Sometimes several different methods of manufacture may be used to produce a given product characteristic. If possible, it is wise to give the manufacturing unit latitude in choosing the method best suited to cost reduction and maximum flexibility. Usually the design engineer specifies the characteristics that affect performance, durability, safety, servicing in the field, and appearance as it is related to public acceptance. These are usually referred to as functional requirements. Non-functional requirements are those that affect the product within the shop or factory. They are often covered by shop practice, standing instructions, methods sheets, and so forth. More latitude usually is possible in dealing with non-functional requirements.

Special problems arise in drawing up specifications for bulk products, such as those encountered in the chemical industry, for example. In such cases, the *average* and *uniformity* of the specified characteristics for the mass need to be considered. Tests are made on a specimen of the bulk product. The test specification should specify the manner in which such a specimen is obtained. The American Society for Testing Materials* (ASTM) has accomplished a considerable degree of standardization in testing bulk products.

4.5 SPECIFYING TOLERANCES

It is practically impossible to manufacture one article exactly like another, or one batch like another. Variability is one of the fundamental concepts of modern quality control. Tolerances on a dimension of a part tell the shop how small or how large the part may be and still fit into the assembly and function properly when it is related to the other parts in the assembly. Tolerances are set not only on dimensions, but also on other quality characteristics as well, such as temperature, pressure, and volume. Tolerances may be stated in several different ways:

$0.262^{+0.006}_{-0.000}$	unilateral
0.265 ± 0.003	bilateral
$0.262 - 0.268$	limiting

Usually a company standardizes on one system.†

* Those requiring a more detailed treatment of the subject should refer to Juran, *Quality Control Handbook,* pp. 49-52.

* American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pennsylvania.

† For a further discussion of tolerances, see Wm. H. Clapp and D. S. Clark, *Engineering Materials and Processes* (Scranton, Pennsylvania: International Textbook Co., 1949), pp. 353-360.

The selection of tolerances is very important. They should not be set needlessly tight, since the cost of manufacture usually rises rapidly as the tolerance is decreased. On the other hand, the tolerance must be set so as to insure interchangeable manufacture, where possible, and to assure proper functioning of the product. Tolerances are set on the basis of (1) past practice, (2) experiment, and (3) bargaining.* Engineers are able to set tolerances more accurately if they are assured that the factory processes will operate in statistical control and if they have available process or machine capability studies (see Art. 18).

Tolerances may be non-numerical as well as numerical. In cases where color, texture, finish, roughness, and the like are involved, it is often necessary to set tolerances by establishing marked visual standards on the permissible degree of an unsatisfactory quality characteristic. Such standards are often established by the standards committee (see Art. 2.5), which decides by vote where the line shall be drawn. The selection of samples for consideration by the committee should cover a wide range of degree of the unfavorable characteristic. Although the manufactured parts may be divided into "go" and "not go," only one standard should be established to "draw a line." If both a "go" and "not go" standard are established, someone is bound to find a specimen that falls between the two. Confusion results. But if one standard is established and is marked "go," then any specimen equivalent to or better than the standard is acceptable. Conversely, if the standard is marked "not go," any specimen equivalent to or worse than the standard is unacceptable.

Great care should be taken to preserve the standard, especially if the quality characteristic represented changes with age. If the standard is "kicked around" the shop, it will not remain a standard for long. It will probably be necessary to keep a master set of standards locked in a cabinet for occasional reference. Working standards can then be established as frequently as necessary by reference to the master set.

Visual inspectors tend to "drift" from the standard. It is sometimes necessary to have the inspectors orient themselves several times a day by studying the standards.

* For a full discussion of these factors, see Juran's *Quality Control Handbook*, pp. 56-60.

4.6 DESIGNATION OF CRITICAL DIMENSIONS

It is often advantageous to designate critical dimensions and other critical quality characteristics. On blueprints this can be done by underlining critical dimensions or by using an asterisk. A copy of the inspection plan for purchased parts is valuable for informing the vendor on the relative importance of the different quality characteristics that have been specified (see Art. 12.3).

4.7 TOLERANCE BUILDUPS IN ASSEMBLY

Unless all component parts fall close to either the upper limit of tolerance or the lower limit of tolerance, the assembly will have a variation that is less than the sum of the tolerances of the components. Use of this fact can be made either to increase the tolerances of the component parts, thereby reducing manufacturing cost, or to decrease the tolerance of the assembly to facilitate further assembly or improve quality.

The ideal case results where the dimensions of each individual piece part are normally distributed about its respective mean and where each distribution lies between its tolerance limits in such a way that the three sigma limits of the distribution correspond to the tolerance limits (see Section 13, Art. 2.3.6). In such an ideal case, and where the parts are randomly selected, the Pythagorean theorem applies—i.e., *the standard deviation of the sum of a number of independent parts is equal to the*

square root of the sum of the squares of the independent standard deviations. Expressed mathematically:

$$\sigma_A = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 \cdots + \sigma_n^2}$$

where σ_A = the standard deviation of the assembly

σ_1 = the standard deviation of the first component part

and σ_n = the standard deviation of the nth component part.

Since the ideal condition described above is not consistently met, actual practice lies somewhere between the Pythagorean theorem and the arithmetic sum of the deviations or tolerances.*

4.8 REVISION OF SPECIFICATIONS

Changing conditions brought about by a variety of causes make it necessary to revise specifications from time to time. Although many units of an organization may instigate revisions, only one unit should be responsible for making them. This is usually the engineering unit.

The number of parts involved and the frequency of changes result in numerous revisions to blueprints and written specifications. Since many units of the organization are involved, and since they must be advised promptly and simultaneously of changes in specification, a convenient, rapid method of publishing changes is essential. Duplicating equipment for part prints and printed matter is a necessity.

Prints and specifications should, of course, be numbered for convenience and reference. Moreover, the *revisions* of prints and specifications should be *numbered and dated* to assure use of the latest revision. This information is logged in a square for this purpose in the corner of the print.

Changes to the master engineering records (prints and specifications) usually involve the republishing of considerable copy and the spending of considerable time. Although it is a temptation to make changes by simple memoranda, difficulties will arise unless the master copies or tracings are kept up-to-date.

A convenient compromise that assures speed in making changes and at the same time provides a routine for changing master records is the use of a standard memorandum form called an "Alteration Notice." This notice is mailed or delivered to all units involved, including the chief draftsman. The copies of the alteration notice then serve as an order to change the master records and to issue revised prints and specifications.

Shop orders should show the revision number as well as the print number and specification number, to assure that the shop is working to the latest revision.

5. QUALITY-MINDEDNESS

5.1 QUALITY-MINDEDNESS: AN ATTITUDE

Quality-mindedness is an attitude toward the importance of quality. Attitudes can be developed or changed. A salesman seeks to influence our attitudes so that we will accept his product with favor. The most powerful approach is to show the individual how he can personally benefit by accepting what is offered.

5.2 THE IMPORTANCE OF QUALITY-MINDEDNESS

Unless all the members of the industrial team have the correct attitude toward quality, little will be accomplished despite excellent inspection facilities and a complete quality control program. As a matter of fact, the quality control program is not complete without quality-mindedness. One often hears the expression "Quality control has to be sold." This is true. Furthermore, it has to be sold at every level in

* F. S. Acton and E. G. Olds, "Tolerances—Additive or Pythagorean," *Industrial Quality Control*, Vol. V, No. 3, November 1948, p. 6.

the organization—not just to management.

5.3 QUALITY-MINDEDNESS IN UPPER MANAGEMENT

Unless top management shows a perpetual interest in quality by word and deed, there will not be an energetic striving for quality out in the shop. Management must be sold first.

The importance of quality, as far as management is concerned, is that it helps build a good reputation in the competitive market. Another good reason why management should want quality-mindedness in the organization is that a reduction in costs can be realized from reduced scrap and rework, lower complaint costs, and so on.

Management must offer more than lip service to quality. It must give sincere attention to quality reports and quality audits. If proper action is not forthcoming to correct out-of-control conditions in manufacturing departments, the manager must call the responsible supervisors into conference to assure corrective action.

5.4 QUALITY-MINDEDNESS AT SUPERVISORY LEVEL

Management relies on the supervisor or foreman to extend the company policies into the shop and to the personnel under the foreman's supervision. Here especially, actions speak louder than words. Does the foreman shut down the job that is producing defectives—even in the face of tight production schedules? Does he look upon the inspector as his helper in matters pertaining to quality, or does he think of the inspector as a policeman or as an obstacle? Does he go around to the persons under his supervision and discuss the quality of their work, complimenting them when it is good, suggesting improvements when it is substandard? In other words, is he interested in seeing that his section produces a quality job? If so, he is quality-minded.

Some of the larger aircraft frame manufacturers have installed an incentive plan for supervisors that provides for bonus based on improved performance. Such quality factors as reduction in scrap and rework are measured and used in calculating the bonus. Since the supervisor finds it to his financial advantage to use quality control techniques, he usually has a favorable attitude toward them.

5.5 QUALITY-MINDEDNESS AT OPERATOR LEVEL

When the individual operators are convinced that it is to their interest to produce quality work, the quality control program finds itself on a solid foundation. When the operator looks upon a control chart as a tool that is helping him to do a better job and hence places him in line for advancement and all that goes with it, you have won his confidence in quality. Until his confidence is won, he may be suspicious that the inspection department is a kind of Gestapo, and that the control chart is a tell-tale. He will do everything he can to beat the game and to sabotage the efforts of the quality program. The operator has to have the correct attitude. When he does, he regains pride in workmanship and takes the rightful share of his responsibility for quality.

> . . . All this means, in practical language, that the bulk of the gauges and test equipment should be in the hands of the operating force and available to them for deciding then and there whether what they are doing is meeting the specification limits. The use of these means of measurement should be urged on the operating force with the repetition and emphasis which will make it second nature. Unless you know what you are doing, don't do it.*

* Juran, *Management of Inspection and Quality Control*, p. 210.

5.6 PROMOTING QUALITY-MINDEDNESS

An occasional promotional drive for quality is a useful device for letting the man in the shop know what management's attitude on quality is. Some promotional programs are quite elaborate, with such devices as beauty contests to choose a "quality queen,"* prizes for quality slogans, extra awards for suggestions that improve quality, and a special dinner for the supervisors as the grand finale. There is no limit to the sales promotional devices that can be used. Even a modest promotion can effectively use the following devices:

1. Short write-ups in plant paper.
2. Cartoons in plant paper.
3. Posters displayed in work area.
   a. General (including cartoons).
   b. How to do it better.
   c. Why do it better.
4. Quality Slogans.
   a. "Quality is Everybody's Job."
   b. "Quality must be *built* into the product, not inspected into the product."
   c. "Quality you can trust."
5. Increased suggestion awards.

The Anaconda Wire and Cable Company* and the Ford Motor Company† have done outstanding promotional work in quality control.

6. QUALITY COSTS

6.1 SCOPE

The income of a manufacturing enterprise is influenced directly by what it has to offer the consumer. On the other hand, if the cost of manufacture is so great as to permit no profit, the enterprise cannot exist. The fundamental elements of income, cost, and profit are inexorably tied to quality. A balance has to be struck between the cost of quality and the value of quality

6.2 MEASUREMENT OF QUALITY COSTS

Although in the preceding section we found that many cost elements have their "quality" aspects, only a few cost elements are considered strictly quality costs. These are:

1. Inspection.
2. Quality Control.
3. Spoilage.
4. Rework.
5. Warranty Expense.

The first two items represent an expenditure by which it is hoped that the cost of the last three items will be decreased.

Even after a satisfactory equilibrium has once been established between the two kinds of costs, certain action may be necessary from time to time to maintain the equilibrium.

A measure of these various cost elements is usually obtained in dollars, in order to give a somewhat direct measure of the effectiveness of the inspection and quality control functions.

In order to get a comparative measure between periods with varying rates of production, or between various manufacturing enterprises, quality costs are usually given as a ratio of dollars quality costs to dollars direct labor cost. This ratio, although fairly common in industry, has a serious drawback. As an industry becomes more mechanized, its direct labor load decreases. When this occurs, the ratio of quality cost to direct labor increases, when actually no change has occurred in dollars of quality cost. This ratio is also poor for comparison between different types of manufacture, because of differences in the direct labor content of the product.

A better measure is the ratio of dollars quality cost to dollars output at manufacturing cost. This includes some measure of cost of quality versus value of

* H. E. Thompson, *Quality Control Conference Papers*, Sixth Annual Convention, American Society for Quality Control, pp. 137-145. Syracuse, New York, May 1952.

† Wm. H. Smith and C. R. Burdick, "Ford's Interest in Statistical Quality Control," *Industrial Quality Control*, Vol. VII, No. 3, November 1950, p. 6.

quality. A number of companies are now using this ratio as a measure for quality costs.

E. L. Grant* has thoroughly discussed many of the economic considerations and cost comparison problems involved in statistical quality control.

6.3 INSPECTION COSTS

The older measure of inspection cost—i.e., the ratio of inspection labor to direct labor—varies widely throughout industry; however, as a general rule the aim is to maintain a ratio of approximately 0.10, or 10 per cent. The ratio is known to vary from 0.05 to 0.25, depending on the type of operation.

The ratio dollars inspection cost to dollars manufacturing output does not have such widespread usage as the preceding ratio; hence, its value in various industries is not known. In small electrical appliance manufacturing, it generally runs from 0.5 per cent to 3 per cent, depending on the type of operation.

As operations become mechanized, and as the labor content of the product decreases, the ratio tends to rise. This rise should be met by mechanizing inspection operations by means of automatic test equipment, sorting machines, and the like (see Art. 9.10).

Because of the importance management attaches to keeping a low ratio, the costs charged to the inspection function are closely scrutinized. In some manufacturing organizations, sorting costs are considered not as inspection costs but as manufacturing costs. The argument is that if the manufacturing process is capable of the assigned job and is operating in control, only a sampling inspection is necessary to evaluate the quality of the material. This evaluation is an inspection function. If the manufacturing process is incapable of meeting requirements and sorting becomes necessary, then sorting is chargeable to manufacturing.

Inspection costs are influenced to a great extent by inspection planning and by establishing economic quality levels throughout the process (see Art. 7).

6.4 QUALITY CONTROL COSTS

The ratio of *statistical* quality control costs to direct labor generally varies from 0.001 to 0.005 (0.1 per cent to 0.5 per cent). This does not include inspection personnel but does include quality control engineers, analysts, clerks, and other personnel occupied in coordinating the quality control function, and in analyzing and reporting data. Quality assurance costs are generally included as part of quality control costs; however, in some larger corporations they may be reported separately.

6.5 SPOILAGE COSTS

Spoilage costs include labor, material, and overhead invested in the spoiled piece part or article. Recovery from sale as scrap is credited, thereby reducing spoilage costs. Thus spoilage includes only piece parts that are junked. If a part can be repaired, it is not included in spoilage. Neither does spoilage include gates, chips, borings, or skeletons (waste inherent to the process of fabrication).

Spoilage ratios vary so widely throughout industry that comparative figures have little value. Usually the ratio is quite low for straight assembly operations where piece parts are purchased and assembled. On the other hand, spoilage might run high where raw materials are being fabricated into parts.

6.6 REWORK COSTS

Rework costs include the material and unapplied labor required to place the rejected part in acceptable condition. Rework ratios also vary

* *Statistical Quality Control,* Chapter XVII.

widely, depending on the type of manufacture; hence comparative ratios have little meaning except within a certain type of manufacture within an industry.

6.7 WARRANTY EXPENSE

Warranty expense is the cost of repairing or replacing the product for the customer under the terms of the warranty or guarantee. This generally includes the cost of repair parts, repair labor, and service overhead. Some manufacturers limit their liability to defective parts only, leaving labor and service cost to the dealer.

In a small percentage of complaints it is sometimes necessary to go beyond the terms of the warranty to maintain customer goodwill. The cost of this service is also charged to warranty costs. Careful judgment is necessary in drawing the line between factory responsibility and customer misuse or abuse.

Warranty expense is an excellent barometer for measuring the effectiveness of the quality control program (see Art. 17).

The ratio of warranty expense to standard manufacturing cost of sales is sometimes used to evaluate and compare warranty expense from period to period or from industry to industry. If quality is good, one would not expect this ratio to exceed 2 or 3 per cent.

7. INSPECTION PLANNING

7.1 WHAT TO INSPECT

As soon as the specification and prints are released by product engineering, it should be possible to start inspection planning. Important quality characteristics should be pointed up in the specification, and critical dimensions should be identified on blueprints. If necessary, a conference with the responsible design engineer should be arranged to define important characteristics with respect to both piece parts and the final product.

Dimensions governing fits should be checked on piece parts prior to assembly. Inspection planning includes determining how a certain dimension is to be gaged so that proper gages can be ordered and procured prior to start of manufacture. Often the tooling and method of manufacture has a bearing on reference points, datum planes, and so on. The gage designer should have a knowledge of the tooling employed.

Where appropriate, electrical characteristics of such components as resistors, condensers, and vacuum tubes, should be determined as to acceptability prior to assembly. In general, any piece part that is "buried" deep in the assembly and difficult to replace in the assembled article should be inspected prior to assembly. In the case of complicated assemblies, involving sub-assemblies, it may prove desirable to give sub-assemblies an operational test prior to incorporating them in the final assembly.

Where raw materials, piece parts, components, or sub-assemblies are purchased, at least an identifying type of inspection is made by the receiving inspector. Generally lot-by-lot acceptance sampling is done on all purchased parts. Here again operational tests may be run on purchased sub-assemblies, particularly if replacing a defective sub-assembly in the final product is difficult or expensive.

In some cases, a defective piece part may not be discernible in a final test or inspection on the complete assembly. If nonconformance of the piece part to specification is likely to cause early failure or affect the quality of the device in some functional manner, prior inspection of the piece part is mandatory. If the destructive nature of testing or high inspection costs make sampling inspection necessary, a plan should be selected that will assure that lots containing an uneconomically high percentage of defectives be limited.

7.2 WHEN TO INSPECT

Purchased parts and raw materials should be inspected when received, prior to being warehoused, stocked, or sent directly to assembly.

When a die, mold, or tool is being set up, first parts should be inspected and an "O.K. to Run" should be given when the first parts are proved to meet requirements. It is also important to check *last parts* at the completion of a run to determine if any work is required for repair of the tool before the next run. Dies, tools, or molds going into storage should be tagged with their status.

While a job is running, it is advisable to make occasional checks by means of patrol inspection or operator inspection. Checks may be made at intervals of several times per hour to once every few hours, depending on how well the process remains in control.

Where a piece part goes through several operations, it is usually uneconomical to inspect after each operation; 100 per cent inspection after each operation can rarely, if ever, be justified. Even an acceptance-type sampling inspection after each operation is difficult to justify. At best, only a patrol type of inspection can be afforded. Or the operator should be equipped with the necessary gages, test facilities, and control charts to permit him to manufacture to specification.

It might be desirable to inspect the item being processed *prior* to a very expensive operation where lack of conformance to specification might mean the loss (scrapping) of the item.

In some cases, it may be impossible to evaluate the quality of one operation until the completion of one or more subsequent operations. For example, the foundryman cannot tell if he has a sound casting until it is subsequently machined.

In general, an inspection is made after a series of manufacturing operations has been performed. Often a logical time to inspect is when the piece part leaves one department or section and enters another section for further processing. An acceptance-type sampling inspection is often possible where processes are operating at satisfactory quality levels. The usual rule is to give the final assembly or finished product 100 per cent inspection, including a final operational test. Where quality is satisfactory and the product is inexpensive, however, 100 per cent inspection may not be justified. In such cases, at least a statistically sound sampling plan can be justified to evaluate and control final product quality.

7.3 WHO SHOULD INSPECT

Receiving inspection is usually assigned to an individual inspector or inspection unit that specializes in the inspection of purchased parts. The unit is equipped with specialized gaging and test equipment to check conformance of purchased parts to specification. The receiving inspector should have the services of the engineering or test laboratories to run physical, metallurgical, and chemical tests where required. The inspection planning sheet should indicate where laboratory tests are required (see Art. 12.3). Laboratory results are reported back to the receiving inspector, who accepts or rejects the received material on the basis of laboratory results, together with other inspections that he has made.

First-part and last-part inspection should be made by qualified precision inspectors.

Periodic inspection during a run should be made by the operator where at all possible. If the inspection is too time-consuming or too specialized to permit the operator to discontinue the manufacturing operation in order to make the inspection, a patrol or floor inspector may be assigned to this activity. A knowledge of the more common precision inspection techniques is usually necessary. Patrol inspection or roving inspection too often becomes aimless unless it is tied in with reports or control charts. Planning should be complete enough to designate specifically the inspection operations and the reporting expected of the patrol inspector.

Completed lots passing from one manufacturing section to another or to stock are submitted to bench or crib inspectors, who perform required sampling

inspection procedures according to established quality characteristics and AQL (Acceptable Quality Level) values (see Art. 11).

Line or conveyor inspection usually employs 100 per cent visual inspection or testing; however, sampling plans are available for continuous processes.*

7.4 WHERE TO INSPECT

Receiving inspecting should be located at the receiving dock in such a manner that the parts must pass through a receiving and inspection room before being moved to storage. In the case of large, heavy, or bulky items, such as telephone poles, this will, of course, not be possible. Stockpiles of such items should be well identified to show whether the material is being held for inspection or has been released.

Patrol inspection, by its very nature, requires the inspector to "call" periodically at the machine for parts to be checked. He may take these to an inspection crib for gaging or he may perform the gaging operation at the machine. The latter procedure is preferable. Mobile inspection benches with necessary surface plates and so forth are convenient and time-saving in large establishments.

Precision inspection is located in a crib or an air-conditioned room.

Inspectors engaged in acceptance sampling should be centralized at one or two locations for better supervision and utilization of inspection equipment. Lots of parts are delivered to this area. Proper factory lay-out will permit such a location to serve several manufacturing sections without back-hauling. The area should also be located so that work entering finished parts stores will have to pass through the acceptance inspection area.

In cases where 100 per cent or detailed inspection is required, higher inspection efficiency will be realized if the inspectors are paced by the machine or conveyor belt than if they remove the work to a bench for inspection.

* Dodge's AOQL Plan and the Dodge-Torrey Plan. See Grant, *Statistical Quality Control*, 2nd ed., pp. 354-358.

7.5 WHAT QUALITY LEVEL?

An important part of inspection planning is the establishment of the AQL (Acceptable Quality Level) for acceptance sampling for each class of item at each inspection station. Although many factors may enter into the determination of AQL values, there are two primary considerations:

1. Sampling inspection will permit passage of a certain small per cent defective if the process causes defectives to be present. Will these defectives be removed during subsequent inspection or assembly operations? If not, will it be feasible to permit these few parts to enter the product undetected on the basis of economy, safety, and quality reputation?

2. If the defective part can be detected as a result of final inspection and test on the completed item, the problem becomes one of simple economics, i.e., comparing the cost of finding a defect with the cost of failing to find a defect.

$$p = \frac{\text{unit cost of detailed inspection}}{\text{unit cost of failure to find defect}}$$

where

p = fraction defective at break-even point.

When p exceeds this ratio, it is cheaper to detail inspect. When p is less than this ratio, it is cheaper to accept the defects. The AQL should be set somewhat tighter (lower fraction defective) than p to allow for inherent risks in sampling when poor quality is submitted. (See Section 11 on Acceptance Sampling.) Generally, AQL values run between 0.5 and 3.0 per cent. One survey* of industries using Military Stand-

* Fay Carlson, "A Survey of the Application of MIL-STD-105A in the Aircraft and Associated Industries," *Quality Control Conference Papers 1952*, pp. 73-79.

ard 105A Sampling Tables showed the following AQL values for various classes of defects described as follows:

Critical	100% Inspection
Major	0.65% to 1.5%
Minor A	2.5%
Minor B	4 to 6.5%

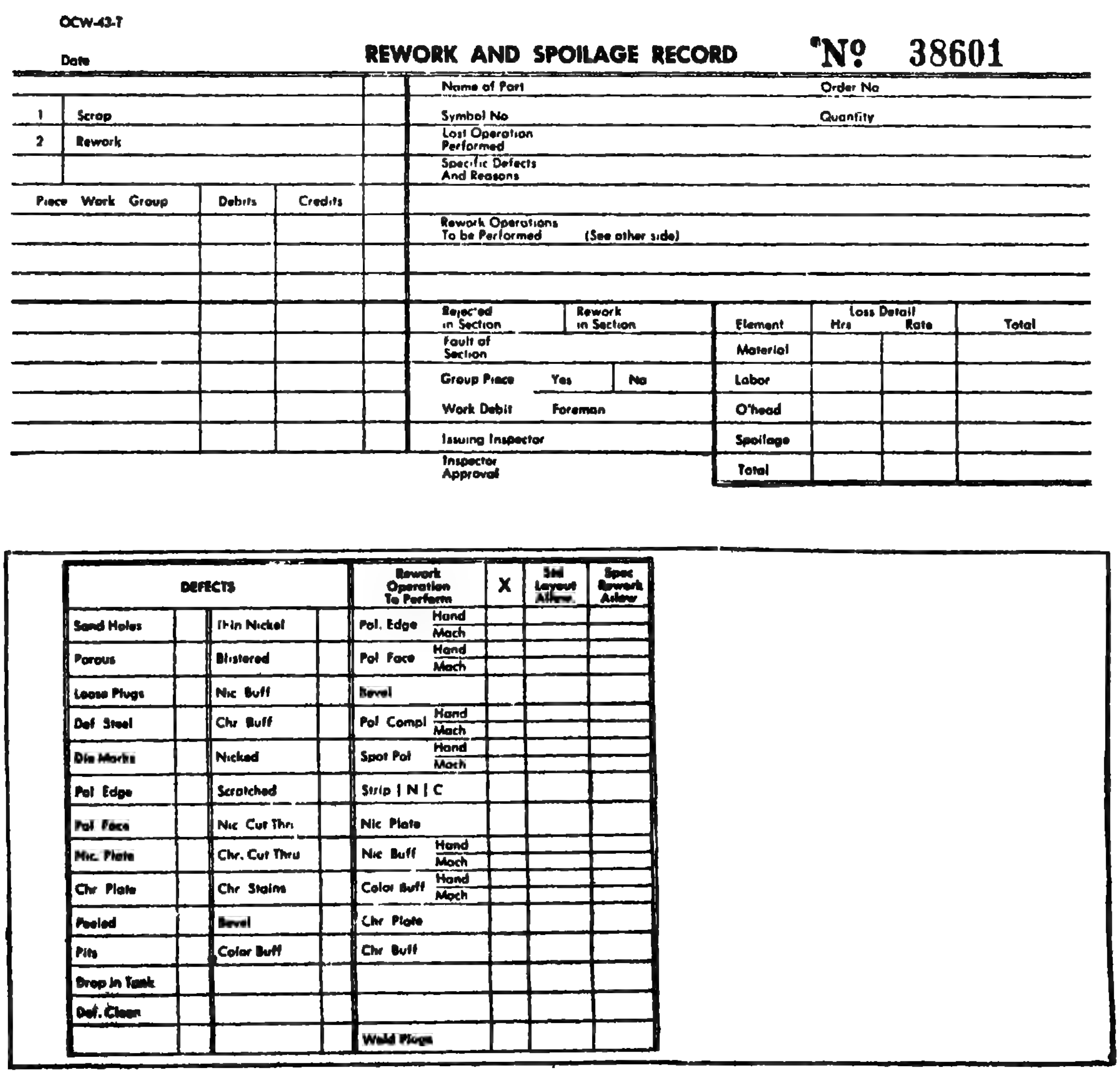
Where AQL values are established for each of a number of quality characteristics on one item, it might be possible for the lot in question to barely meet the AQL for each characteristic but when taken as a whole to be several per cent more defective than desired. Where this threat exists, it is advisable to specify not only the AQL for each quality characteristic, but also a limiting AQL for *total defects.*

7.6 INSPECTION PLAN FORMS

When all the above planning factors have been determined, the plan should be specified on a suitable form for each piece part or assembly. It should show opposite each manufacturing operation, where applicable, the characteristic to be inspected, the gages or equipment used, reports and charts used, and the inspection procedure.

It is also important to have inspection operations appear on process lay-out

FIG. **14.5** REWORK AND SPOILAGE RECORD.


OCW-43-T

Date

REWORK AND SPOILAGE RECORD *№ 38601

1	Scrap
2	Rework

Piece Work Group	Debits	Credits

Name of Part

Order No

Symbol No

Quantity

Last Operation Performed

Specific Defects And Reasons

Rework Operations To be Performed (See other side)

Rejected in Section

Rework in Section

Fault of Section

Group Piece Yes No

Work Debit Foreman

Issuing Inspector

Inspector Approval

Element	Loss Detail Hrs	Rate	Total
Material			
Labor			
O'head			
Spoilage			
Total			

DEFECTS				Rework Operation To Perform	X	Std Layout Allow.	Spec Rework Allow
Sand Holes		Thin Nickel		Pol. Edge Hand / Mach			
Porous		Blistered		Pol Face Hand / Mach			
Loose Plugs		Nic Buff		Bevel			
Def Steel		Chr Buff		Pol Compl Hand / Mach			
Die Marks		Nicked		Spot Pol Hand / Mach			
Pol Edge		Scratched		Strip | N | C			
Pol Face		Nic Cut Thru		Nic Plate			
Nic. Plate		Chr. Cut Thru		Nic Buff Hand / Mach			
Chr Plate		Chr Stains		Color Buff Hand / Mach			
Peeled		Bevel		Chr Plate			
Pits		Color Buff		Chr Buff			
Drop in Tank							
Def. Clean							
				Weld Plugs			

Courtesy General Electric Company.

INCOMING MATERIAL INSPECTION RECORD

Vendor__________ Part __________ Dwg. No.__________

RECEIVER NO	REC. DATE	LOT SIZE	DEFECT NO			SAMPLE				100%	% DEF	REMARKS	DISPOSITION	INSPECTOR
			TEST	CRIT	MAJOR	1ST		2ND						
						N	M	N	M	N				

Courtesy General Electric Company.

FIG. **14.6** INCOMING MATERIAL INSPECTION RECORD.

cards, routing tags, and other "paper" governing movement of the parts through the factory.

8. INSPECTION AND QUALITY CONTROL REPORTS

8.1 SCRAP AND REWORK TAGS

Rejected lots in the factory are identified by a distinctive cardboard ticket. One or two carbon-backed paper copies overlay the cardboard. The paper copies go to the office for accounting and quality control use. The cardboard ticket stays with the work. Figure 14.5 shows a typical form for such a tag.

These tags can be tabulated to form a weekly summary of scrap and rework In large installations, the summary may be made from key punched cards.*

* Juran, *Quality Control Handbook,* Section 9, "Applications of Electric Accounting Machines to Quality Control."

8.2 RECEIVING INSPECTION RECORDS

Inspection records are usually filed by part number, by vendor, or both. A card file using the form shown in Fig. 14.6 has proved convenient.

From these cards a quarterly summary can be made whereby each vendor is given a quality rating based on percentage of lots accepted, or on some other suitable measure of quality. Where double or multiple sampling plans are used, first sample inspection results should be separately recorded for statistical analysis. To avoid "weighting" from lots requiring second samples, *p* charts (see Section 13, Art. 2.6) should be based on first samples only. The form shown in Fig. 14.6 was designed to be used with the Quality Control Inspection Plan shown in Fig. 14.14, Art. 12.3.

8.3 SAMPLING INSPECTION RECORD

A sampling inspection record for recording results of acceptance sampling within the factory and between

GENERAL ELECTRIC CO.
Ontario Works

Sampling Inspection Record Section ______

Date	Part Number	Part Name	AQL %	Lot Size	1st Sample		Total Sample		Disp. P or R	Detailed		Description Of Defects	Insp. by
					No. Insp.	No. Def.	No. Insp.	No. Def.		No Insp.	No. Def.		

Courtesy General Electric Company.

FIG. **14.7** SAMPLING INSPECTION RECORD.

operations or departments is shown in Fig. 14.7.

8.4 PATROL INSPECTION LOG

A patrol inspection log consists of a printed form headed with the following information: Section, Shift, Date, and Inspector. Required information is entered in columns headed: Part No., Part Name, Operation, Die Serial No., Time Job Was Stopped or Held Up, Reason, Time Released.

In some cases, the log may consist of a timetable on which are entered the results of each call at each machine or process.

8.5 FINAL INSPECTION REPORT

In most cases, the final inspection report will be based on the results of a detailed (100 per cent) inspection of the final product. The form used consists of a list of classified defects for the specific product and a space to enter the total number of defects encountered in each classification. Space is provided for other necessary information, such as: Section, Shift, Date, Inspector, Total Number Inspected.

8.6 OTHER SPECIALIZED REPORTS

There are many other kinds of reports by which inspection and quality control information is recorded and transmitted to individuals in the organization. To conserve space and avoid repetition, these other types of reports are listed below with reference to the articles in which they are mentioned.

Type of Report	*Article Reference*
Gage Record	9
Record of Measurements ($\bar{X}$,R)	10
Per Cent Defective	10
Quality Audit	13
Life Test	14
Salvage	16
Field Reports	17
Machine Capability	18

9. MEASUREMENTS AND GAGING

9.1 NATURE OF MEASUREMENTS

The specification defines the quality characteristics that a product is to have. The presence or absence of the characteristic, or the *degree* to which it is present or absent, is determined by one or more of the human senses, i.e., sight, sound, feel, taste, smell. When the characteristic cannot be detected or measured directly by one of the senses, it is necessary to transform the characteristic into some phenomenon that can be sensed by means of suitable instruments, apparatus, or test equipment. For example, a wattmeter transforms watts into length (on a scale) that can be evaluated by sight.

Sometimes it is possible to detect a characteristic but impossible to evaluate it by the unaided human senses to a sufficiently fine degree. In such cases, an instrument, apparatus, or gage may be used to *multiply* the phenomenon. The micrometer employs a screw to multiply length so that 0.001 inch between the anvils is approximately $\frac{1}{16}$ inch on the thimble.

Many instruments both *transform* and *multiply* the characteristic to be evaluated.

9.2 SENSITIVITY OF MEASUREMENTS

As a general rule of thumb, the instrument should be sensitive enough to permit dividing the total allowable range of the characteristic into tenths. For example, a 1,000-watt electrical heating unit with a tolerance of ± 50 watts would have a total allowable range of 100 watts. The wattmeter should be capable of measuring down to 10 watts. Scale divisions should be at a minimum of 10-watt intervals.

9.3 PRECISION OF MEASUREMENTS

A measuring instrument may lack precision for two different reasons:

1. Miscalibration (not properly set against the standard).
2. Inability to reproduce measurements.

The inaccuracy of the first classification is a constant "error" for a certain position on the scale of the instrument. It is possible to apply a "correction" to the reading equivalent to the error and of opposite sign. The error is determined by taking a long series of readings against a true standard and determining the average of the difference between the readings and the true value.

The inaccuracy of the second classification is due to a scatter of numerous measurements made repeatedly under the same conditions on the same unit of product. This scatter is called the standard deviation of the measurement and may be designated as $\sigma_{\text{meas.}}$ (See Table 13.2, Section 13, for an illustration of the calculation of standard deviation.) The lower the standard deviation of the measurement, the more precise the instrument. In general, the standard deviation of the measurements should not exceed one-tenth the standard deviation of the observed data. If this is the case, the effect on the standard deviation of the product is less than 1 per cent.*

9.4 INSTRUMENT TOLERANCE: GAGE TOLERANCE AND WEAR ALLOWANCE

In Article 9.3, we recognized that all measuring instruments have varying degrees of precision and that requirements for precision vary with regard to product tolerance. We can see the necessity, then, for specifying instrument tolerances. The 1 to 10 ratio may be applied as a general rule (see Art. 9.3), but in certain fields definite tolerances have been specified, especially in the field of fixed gages.

In modern systems, the gage tolerances are all taken inside the product tolerances, so that the gage-maker's tolerance and the wear allowances on gages all operate to reduce the effec-

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* $\sigma_{\text{prod.}} = \sqrt{\sigma_{\text{obs.}}^2 - \sigma_{\text{meas.}}^2}$ Juran, *Quality Control Handbook*, pp. 199–203.

TABLE 14.1 ARMY ORDNANCE SYSTEM FOR INSPECTION GAGES*

Component	Gage		
		Tolerance	
Total tolerance	Wear allowance	Go	Not go
0.0005	0.0000	0.00005	0.00005
0.001	0.0001	0.0001	0.00005
0.002	0.0001	0.0001	0.0001
0.003	0.0001	0.0002	0.0001
0.004	0.0002	0.0002	0.0002
0.005	0.0003	0.0002	0.0002
0.006	0.0004	0.0002	0.0002
0.007	0.0004	0.0003	0.0002
0.008	0.0005	0.0003	0.0002
0.009	0.0005	0.0004	0.0002
0.010	0.0005	0.0005	0.0003
0.012	0.0006	0.0006	0.0003
0.014	0.0006	0.0008	0.0004
0.015	0.0006	0.0009	0.0005
0.016	0.0006	0.0010	0.0005
0.018	0.0006	0.0010	0.0006
0.020	0.0006	0.0010	0.0007
0.022	0.0006	0.0010	0.0008
0.024	0.0006	0.0010	0.0009
0.025 and up	0.0006	0.0010	0.0010
Gagemakers' tolerance, flush pin and adjustable snap gages			
0.0005		0.00005	0.00005
0.001		0.00005	0.00005
0.002		0.0001	0.0001
0.003		0.0001	0.0001
0.004		0.0002	0.0002
0.010		0.0003	0.0003
0.015		0.0004	0.0004
0.020 and up		0.0005	0.0005

* Wear allowances and gagemakers' tolerances, plain plug and plain ring inspection gages, including plain ring gages for major diameter of screws, and plain plug gages for minor diameter of nuts.

tive tolerance available to the manufacturing department.

Tolerance values for one system developed by the U. S. Army Ordnance are given in Table 14.1.

Several different systems of gage tolerances are discussed by Juran.* A good discussion of the American Gage Design Standard has been presented by Kennedy.†

* *Quality Control Handbook*, pp. 204-210.

† *Inspection and Gaging* (New York: The Industrial Press, 1951), pp. 127-129.

Most systems provide for inspection gages and working gages. Tolerances and wear allowances are allocated so that, under specified conditions, work accepted by the working gage will be accepted by the inspection gage.

9.5 GAGES: TYPES AND USE

Gages can be classified on the basis of several different factors:

1. Type of measurement (fixed or variable).

2. Sensitivity or discrimination (0.001 or 0.00001 inches).

3. Method (direct, electrical indicating, air indicating, optical, etc.).

4. Characteristic being checked (depth, thread, spline, radius, etc.).

There are so many kinds of gages and inspection equipment that space does not permit a detailed description of each and the techniques for using each.* (See Section 10, Tool Engineering.)

9.6 GAGES: SELECTION OF FIXED GAGES VS. INDICATING GAGES

Fixed gages (such as plain plug gages, ring gages, adjustable snap gages) merely tell whether the part is undersize, within limits, or oversize. On the other hand, indicating gages (such as micrometers, dial indicators, and so forth) give much more useful information, telling where the process is set and how much variation is occurring. Indicating gages are necessary for process control where small periodic samples are measured and charted (see Art. 10). Fixed gages are suitable for little more than sorting. Since modern quality control emphasizes control of the process and avoidance of defects and sorting, the trend is away from fixed gages and toward indicating gages. Further advancement will lead in the direction of recording and process-regulating types of instruments. (Such devices are already well advanced in the chemical industry.)

* Those interested in the details of this specialized field are referred to the following items: Kennedy, *Inspection and Gaging;* Leno C. Michelon, *Industrial Inspection Methods* (New York: Harper and Brothers, 1942); Wesley Mollard, *Essentials of Precision Inspection* (New York: McGraw-Hill Book Company, Inc., 1944); *Precision Measurement in the Metal Working Industry,* Prepared by the Dept. of Education of International Business Machines Corporation (Syracuse, New York: Syracuse University Press, 1952).

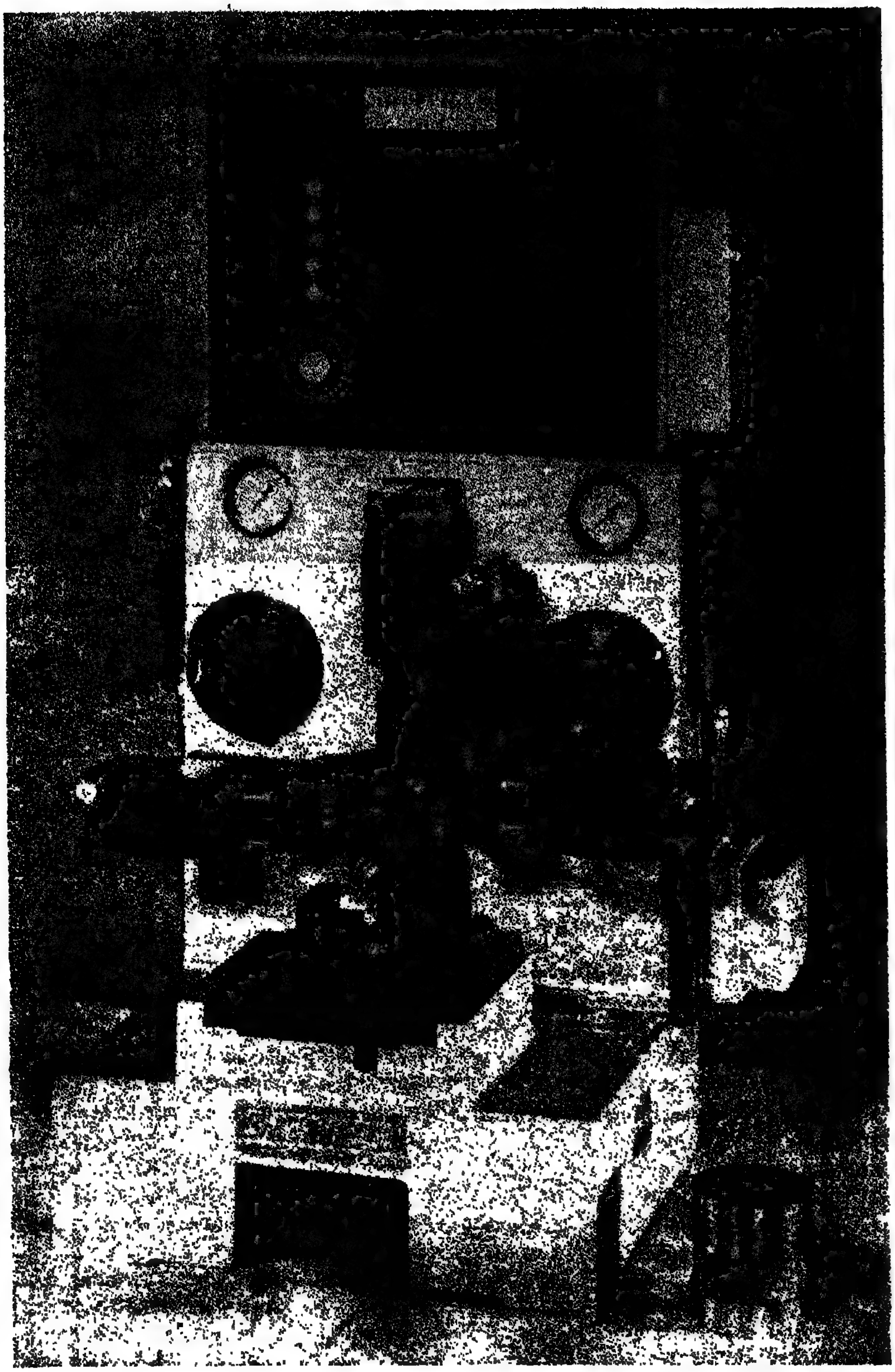
9.7 GAGES: SELECTION OF SPECIAL-PURPOSE VS. GENERAL-PURPOSE

Basic inspection equipment includes a surface plate, precision gage blocks, V-blocks, surface plate square, vernier height gage, and sine-bar. (Of course, the importance of the micrometer should not be overlooked as a basic, general-purpose, measuring device.) The small job shop doing a variety of short-run orders would probably not go much beyond this basic equipment. As the volume of precision inspection increases, it may be advisable to continue to adhere to general-purpose equipment, supplementing the basic equipment with dial indicator stands, mechanical, electrical, or air-indicating gages, and an optical comparator.

In large establishments that mass-produce long-run orders, special-purpose gages can be justified by the saving they make in set-up time over the time required to set up general-purpose measuring equipment. Also, in order to reduce the load on the skilled precision inspector, special-purpose gages can be placed at the disposal of the operators or floor inspectors. Proper instruction must of course be provided in the use of these gages.

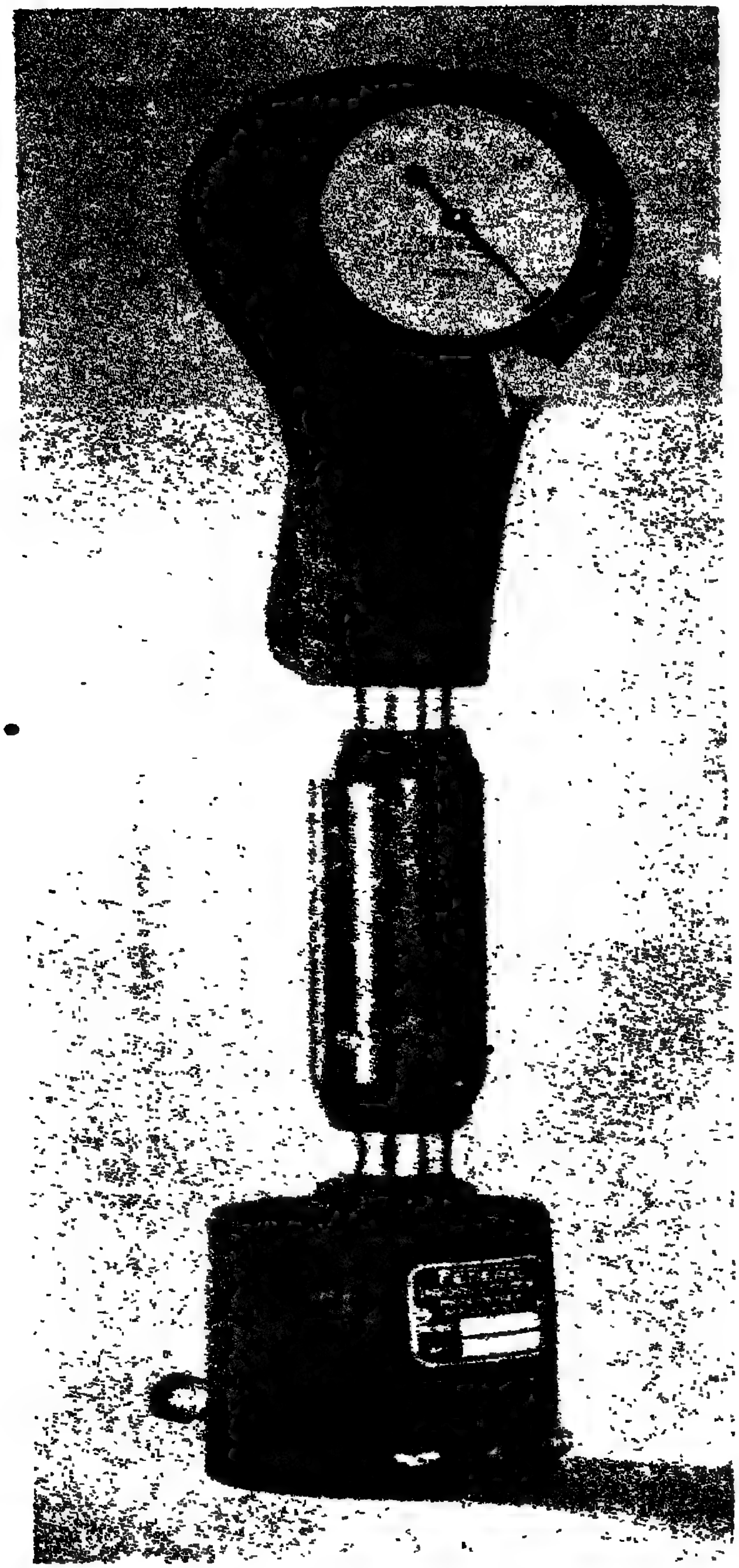
Even special-purpose gages should employ general-purpose units (dial indicators) where possible. This practice has the advantage of permitting conversion of measuring units to other jobs when the need for the special-purpose gage has passed. Such special-purpose gages may consist of several general-purpose gaging units combined to check several dimensions simultaneously. Figure 14.8 shows an example of such equipment.

Indicating bore gages, such as the one shown in Fig. 14.9, not only provide for variables measurement where attribute measurement was formerly used, but also provide a multiple-purpose gage. (Another advantage is that the variable of "feel" is taken care of by the spring-loaded gaging members, which assure a constant gaging pressure.)



Courtesy The Sheffield Corporation.

FIG. 14.8 SPECIAL PURPOSE GAGE CHECKING SEVERAL DIMENSIONS SIMULTANEOUSLY.



Courtesy Federal Products Corporation.

FIG. 14.9 PLUG TYPE, PORTABLE INDICATING GAGE.

Such gages may seem expensive initially, but they are actually economical in the long run because they are useful indefinitely and need not be discarded after a product design change or the introduction of a new model.

9.8 LIMITING USE OF GAGES

In general, gages are quite expensive not only from the standpoint of initial cost, but also from the standpoint of maintenance and use. Hence, they should be used only where necessary—i.e., on dimensions of critical or major importance that are likely to move outside specified limits. In some cases, the need for a gage can be obviated by properly controlling tooling. A safeguard against nonconforming parts might be automatically obtained in subsequent operations. For example, a punch press part that is to go into a spot-welded assembly might have a critical dimension checked by suitable blocks or pins on the welding fixture.

9.9 GAGE AND INSTRUMENT MAINTENANCE

If the accuracy of a gage or an instrument is to be assured, periodic checking and recalibration are necessary. The system is set up and maintained as follows:

1. Identify each instrument by number.
2. Establish a card record for each instrument, showing:
   a. Instrument number.
   b. Frequency of check.
   c. Calibration limits.
   d. Check results.
   e. Location.
   f. To whom assigned.
3. Review card record to:
   a. Assure adherence to checking schedule.
   b. Locate troublesome gages or instruments for redesign or carbide gaging surfaces.

Frequency of check has to be determined on the basis of several considerations, such as: sensitivity of instrument, stability, frequency of use, nature of use, location with respect to dust, and moisture. Experience enables one to revise the schedule to assure an optimum checking interval.

A convenient scheme for scheduling is to have indices in the card file for each day of the week, each day of the month, and each month of the year. Instruments or gages on a weekly schedule can be distributed to the days of the week, those on a monthly schedule to the days of the month, and those on a yearly schedule to the months of the year. Duplicate card files can be set up on the basis of gage number, others on basis of part number, and still others on basis of gage size. Such a plan will provide adequate cross-indexing.

9.10 AUTOMATIC GAGING

In some cases, the requirements of a product are so stringent that they are far beyond the capabilities of the process. Such a product must be sorted. Good examples are the automatic sorting of balls for ball bearings, wrist pins for automobile engines, and rolls for roller bearings. Figure 14.10 shows a machine for sorting roller-bearing rolls.

These are merely examples that point the way. Mechanization of manufacturing processes and assemblies is going forward at a rapid pace. Inspection operations must also be mechanized to stay abreast of the times and to retain proper cost ratio. The use of photoelectric cells, selsyn motors, solenoids, electronic circuits, beta-rays, and a host of other scientific developments excites the imagination on what can be accomplished in the field of automatic inspection.

Already there are numerous examples of automatic inspection operations, such as the automatic stamping of an identification mark (defective) on a unit that fails to meet certain electrical requirements, the continuous monitoring of

Courtesy Federal Products Corporation.

FIG. **14.10** AUTOMATIC GAGING OF ROLLS FOR ROLLER BEARINGS.

sheet steel thickness by beta-rays, and the monitoring of enamel thickness by means of a magnetic circuit. Such automatic equipment should be checked at hourly intervals by running a "known" product through to see whether it is properly accepted or rejected.

10. PROCESS CONTROL

10.1 OBJECTIVES OF PROCESS CONTROL

The primary function of the quality control activity is the *prevention of defects.* This function is best served by effective process control. If the process is statistically controlled at the proper levels with respect to the specification for a certain characteristic, no defectives will be produced—at least with respect to that quality characteristic. Such an ideal situation would mean no scrap, no rework, no detailed inspection or sorting, and product to specification. These are the objectives of process control.

10.2 FUNDAMENTAL CONCEPTS OF PROCESS CONTROL

No process can produce one unit exactly like another unit time after time. Although a process may appear to be quite precise, a sensitive enough measurement of a quality characteristic reveals an inherent variation in the product. This variation in the product is due to variation in the process. Even a simple process involves matter and energy by which some physi-

cal or chemical change is made on the article or substance being processed. Since there is an inherent non-uniformity in matter, and since the release or conversion of energy is influenced by heat, pressure, and other variable factors, it is impossible to divorce the process from the ever-present *cause system* that brings about variability. Although statistical quality control recognizes this inherent variability, it also recognizes that such variability follows a characteristic *pattern* for a given process and that the variation falls within certain limits. The *process pattern* is determined by measurements of the quality characteristics of the product. It is generally necessary to measure 100 or more items to realize a sample of sufficient size to give a truly representative pattern. In the majority of cases encountered in industry, this pattern approximates the normal frequency distribution (see Section 13).

There are two features of the frequency distribution (pattern) that are of primary interest:

1. The spread of measurements (also called "scatter" or "dispersion").

2. The placement of the mean or average with respect to some scale of measurement.

The first feature is measured by a statistic known as the standard deviation and designated by the Greek lowercase letter sigma (σ). (See Section 13.) This measure of spread tells us whether the normal process variations are such as to permit the manufacture of product within specification limits. (The total tolerance should be equal to or greater than 6σ of the process. See Art. 18, Process Capabilities.)

The second feature is measured by the arithmetic average and is *set* at the proper level or is *directed* at the desired value.

Besides knowing what the pattern is for the process, we are interested in the *stability* of the pattern and hence the *stability of the process.* A periodic increase or decrease in spread or a shift in mean (setting) of the process tells us that it is *unstable*. If a process is a controlled process, it must be a stable process. (In some cases where a change in spread or mean can be predicted and adjusted for, the process can be held in control. An example is a shift in turned diameter due to tool wear. A periodic adjustment or sharpening of the tool will prevent too great a departure from the desired mean.)

When the process is stable and produces a consistent, non-changing pattern of variation, the process is said to be operating under a *constant cause system.** Under these conditions, the process is said to be in a state of statistical control and its future performance can be predicted. If, on the other hand, a shift in the normal pattern of variation occurs, the process is said to be operating under an *assignable cause system*. In other words, one or more extraneous causes for variation exerted their influence on the process. These causes can usually be identified with the help of quality control charts that tell when the extraneous cause entered the system. If these charts show a lack of statistical control, the future performance of the process cannot be predicted and the process is said to be erratic or unstable. Figure 14.11 shows the chart patterns for various conditions of the process.

10.3 QUALITY CONTROL CHARTS FOR PROCESS CONTROL

The construction of $\bar{X},R$ charts and p charts has been covered in Section 13, on Industrial Statistics. Control chart limits formulae and factors were tabulated in Table 13.4, page 786. It will be noted that the $\bar{X}$ charts for variables measurements use *averages* of subgroups of individual measurements. This practice gives greater sensitivity to the chart for detecting shifts in mean than if individual measurements were plotted. It has a disadvantage in that

* Some authorities also call this a *chance cause system,* on the basis that all variation under a constant cause system is due to chance variation.

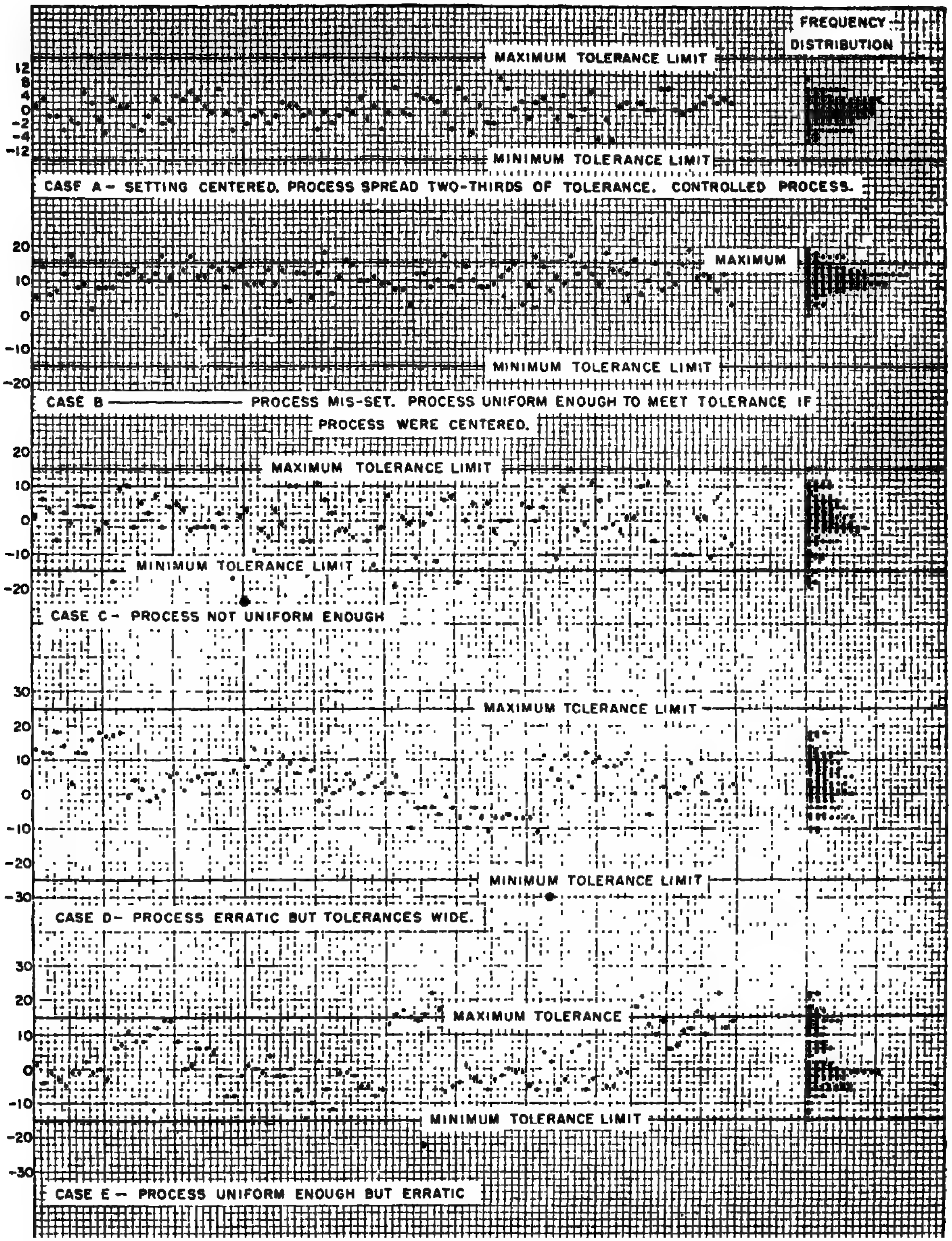


FIG. **14.11** CHART PATTERNS FOR VARIOUS CONDITIONS OF THE PROCESS.

the points on the chart show *average* measurements instead of individual measurements. Shop personnel are accustomed to thinking in terms of individual measurements and the specification is always referred to individual measurements. Some quality control operators believe that the $\bar{X},R$ chart should be used only as a "laboratory tool" for quality control analysts; others feel that it is a very valuable tool for the operator in the shop. Still others try

	A	B	C	D	E
22					2
21					1
20					0
19		1			0
18		2		3	1
17		6		2	3
16		2		1	2
15		4	1	0	2
14		6	0	1	5
13		9	0	2	2
12		15	0	6	2
11		10	4	4	3
10		7	4	3	5
9	1	13	2	5	0
8	0	9	0	3	3
7	0	5	4	5	3
6	6	3	5	5	4
5	3	2	5	7	3
4	4	1	6	3	1
3	11	3	4	6	0
2	10	1	4	4	3
1	9	0	8	6	4
0	10	1	4	7	5
-1	12		7	4	11
-2	8		9	4	6
-3	7		8	0	6
-4	7		0	5	3
-5	1		8	0	7
-6	7		5	3	7
-7	2		2	7	1
-8	0		0	0	3
-9	2		1	0	0
-10			3	2	1
-11			3	2	0
-12			1	0	1
-13			1		1
-14			0		0
-15			2		1
-16			0		
-17			1		
-18			2		
-19			1		
-20			0		
-21					
-22					
tal	100	100	100	100	100

FIG. **14.11** CONTINUED.

to circumvent the difficulty by using "dot charts" for individual measurements. However, these are not nearly so effective, from a statistical standpoint, as $\bar{X},R$ charts.

Certainly if the process is going to be effectively controlled, the operator must know frequently and promptly what the process is doing so that he can make necessary adjustments at the proper time. *The control chart should be at the location of the process and under the constant observation of the operator.* If the operator is trained to take proper action when a point falls outside control limits, the control chart has served its purpose. It does not matter if the control limits are based on average of subgroups so long as correct action is obtained at the correct time in order to maintain control of the process. A useful device to avoid confusion between averages and individual measurements is to cross-hatch the area outside modified

Case A

+1	-3	-7	-6	+4	-1	-4	+2	-6	-1	-1	+3	+6	-4	-3	+4	-9	0	+6	+2
+3	-4	+8	-1	+3	+6	-2	+1	-1	+3	+6	+3	+3	+9	+2	-2	-3	+2	0	+4
-2	+5	+1	+3	+5	-1	-1	+1	-4	-3	-1	+2	-7	+6	+3	-6	-9	0	-1	+2
-2	+2	+1	-4	+3	-6	-4	-2	-2	+1	-2	-1	+1	0	0	0	+1	0	0	+3
-6	-3	-5	-3	+1	0	-2	-1	0	-6	+4	-6	-4	+2	-3	+5	+2	+6	+1	+2

Case B

+5	+17	+8	+11	0	+14	+9	+13	+12	+15	+9	+12	+10	+9	+9	+9	+9	+16	+12	+12
+19	+8	+8	+10	+13	+13	+9	+4	+18	+10	+7	+8	+14	+11	+17	+17	+18	+6	+9	+11
+6	+9	+12	+12	+17	+8	+9	+12	+6	+10	+7	+10	+10	+13	+14	+12	+13	+10	+15	+7
+7	+2	+12	+17	+11	+13	+13	+12	+11	+11	+3	+17	+8	+15	+7	+14	+13	+15	+19	+12
+12	+8	+13	+11	+11	+14	+9	+5	+16	+9	+12	+8	+8	+3	+11	+12	+12	+7	+11	+3

Case C

+1	-1	-1	+5	+5	-2	+3	-1	+11	-5	+7	-1	-18	-3	+4	+9	+6	+1	+11	+1
+6	+4	-18	+2	+3	+2	-9	+10	+6	+6	-19	+2	0	0	0	+15	-2	+10	-10	-11
+3	+4	+9	+7	-3	-2	-3	+10	+2	-6	+1	-12	+5	0	+4	-3	-1	+11	-10	+7
-6	+4	+10	-2	-2	-17	-5	-6	-3	-13	-1	+6	-2	-7	-15	-1	-3	-6	-10	-5
+2	-3	-2	+4	-2	+1	+3	-6	-3	-2	-11	+7	+5	+5	-11	+11	+1	-15	+1	-7

Case D

+13	+3	+17	+1	+6	+6	+8	+11	-2	+3	0	-4	-7	-7	-7	+11	+11	0	-1	0
+12	+12	+17	-2	+1	+3	+13	+9	+1	0	+5	-4	-10	-7	-11	+2	+8	+7	0	+3
+12	+12	+18	-1	+4	+10	+7	+6	0	+5	0	-6	-4	-6	+11	+5	+8	-6	+2	-2
+18	+16	-1	+1	+5	+7	+9	+10	+2	+1	-10	-1	-7	-7	+7	+12	+9	+5	+9	-2
+14	+18	+4	+5	+6	+10	+1	+7	+6	+3	-4	-4	-11	-7	+4	+9	+12	+2	+5	+3

Case E

+1	-1	-3	+8	+8	+5	+1	-2	+2	-2	+13	+16	-4	-3	-5	-3	-13	+18	+6	+10
-4	-1	+6	+10	0	-2	0	0	-6	-5	+16	+22	+1	-2	-6	+5	-5	+21	+7	+15
-1	+2	+7	+11	+1	-8	-1	-6	-12	-5	+17	+17	-3	0	+5	+7	-5	+13	+11	+22
-3	-1	+11	+14	+6	-8	+4	-15	-1	-8	+15	-7	-4	-1	+2	-6	-1	+10	+12	+12
-5	0	+8	+14	+6	-2	-2	-10	-1	-6	+14	-5	-6	-1	-6	-3	-1	+14	+17	+14

FIG. **14.11** CONTINUED.

control limits* (based on the specification) and label such area "Out of Bounds." Figure 14.12 shows such a chart. Although points are falling outside statistical control limits, indicating a shift in mean, the prediction is that with $\bar{R}$ maintained the process average has not shifted sufficiently, as yet, to cause individual items to be outside the specification limits of 2.00-10.00 ounces. The R chart gives a measure of spread for the process. It is related to the standard deviation of the process by the formula

$$\sigma' = \frac{\bar{R}}{d_2}$$

where σ' = standard deviation of the process
$\bar{R}$ = average range
d_2 = factor dependent on subgroup size. (See Table 13.4.)

* Edward M. Schrock, "Modified Control Limits," Chapter XI in *Quality Control and Statistical Methods* (New York: Reinhold Publishing Corporation, 1950), pp. 128-137.

What has been stated for $\bar{X},R$ charts as far as location of the charts is concerned also applies for per cent defective charts (p charts), number of defectives charts (pn charts), or number of defects per sample charts (c charts).* Unfortunately, the latter charts require a larger sample size than does the $\bar{X},R$ chart to provide sufficiently accurate information. Because of this, points are usually not plotted on p charts as frequently as in the case of $\bar{X},R$ charts. Often points on p charts are based on the results of the total inspection for the day. Production figures and number of rejects are not available until the end of the shift and go into the quality control office the following morning. It is usually noon of the day following production before results of that production are charted. If an investigation is necessary before action can be taken, a delay of several days may result before corrective action is realized. Ob-

* p, pn, and c charts are presented in Section 13 on Industrial Statistics.

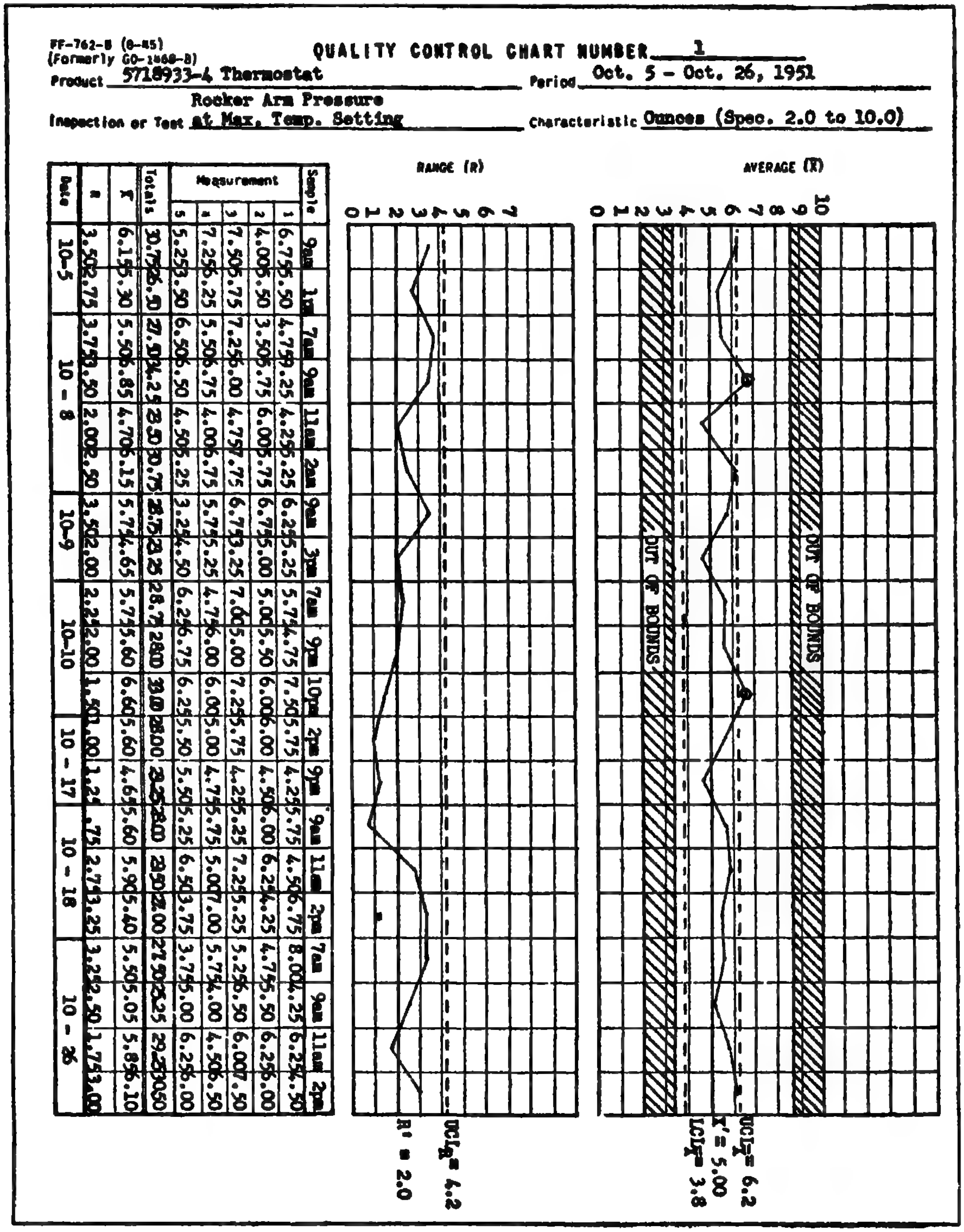
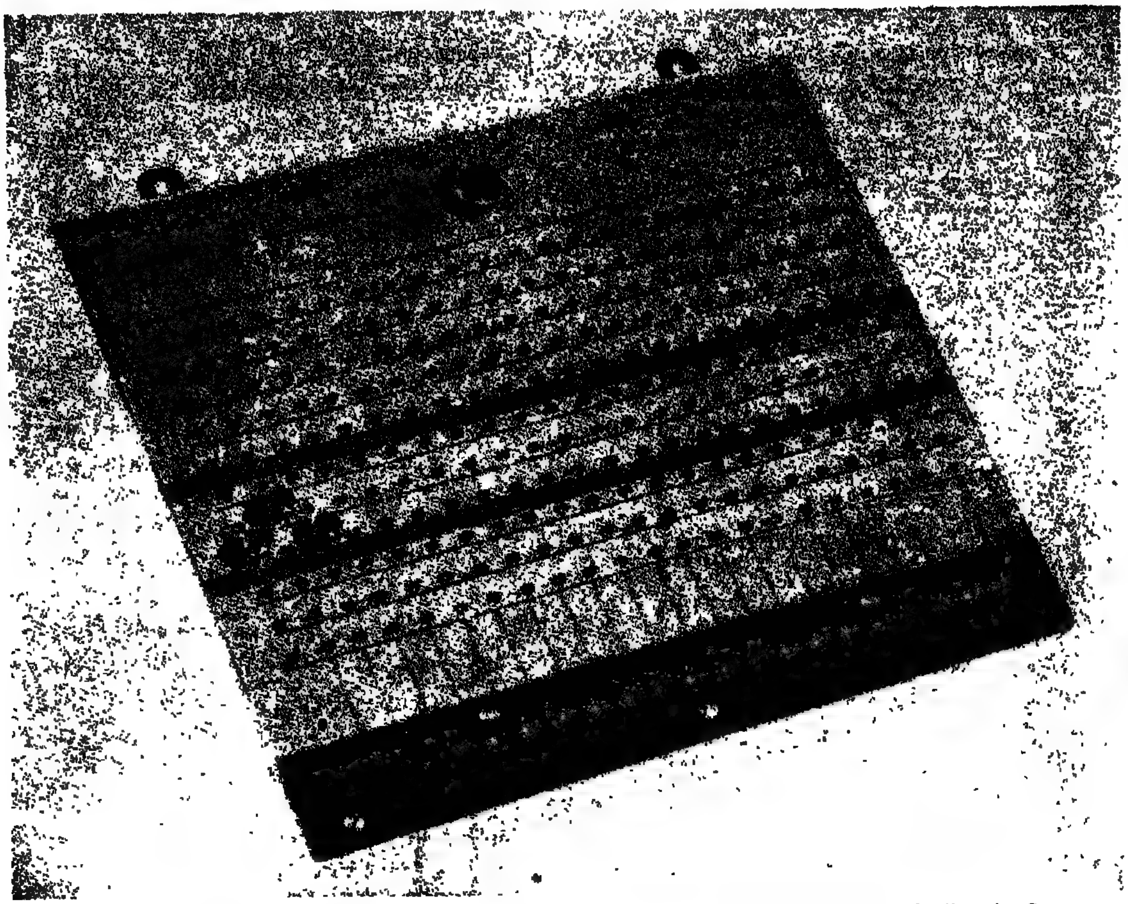


FIG. 14.12 $\bar{X}$, R CHART WITH CONVENTIONAL AND MODIFIED LIMITS (CROSS HATCHED AREA OUTSIDE OF MODIFIED LIMITS).

viously the lines of communication are too long and take too much time. A quality control indicator* has been developed into which is fed continuously the number of units passing through an inspection point and into which the

* General Electric Publication, *Bulletin GEC-629* (Section 687-63), General Electric Co, Schenectady, New York. R. C. Miles, "The Quality Control Indicator," *Industrial Quality Control*, Vol. VI, No. 5, March 1950, p. 16.



Courtesy General Electric Company.

FIG. **14.13** QUALITY CONTROL PUNCH BOARD FOR *pn* CHART.

inspector feeds the number of rejects for a given characteristic by merely pressing a button each time a rejection for that characteristic occurs. An electrical meter on the front of the device interprets the data to show whether or not the process is operating above or below the upper 3σ limit of the p chart and to what degree. This gives instantaneous information at any time during the period of operation (inspection). Investigation and corrective action can be started at once when the pointer of the meter approaches or exceeds the limit.

Another device that can be used to speed up pn chart information is the punch board or peg board shown in Fig. 14.13. A sample of fixed size is taken at hourly intervals from the process. The number of defectives found in the sample is indicated by a peg moved into the row indicating 1, 2, 3 or whatever number of defectives was found in the sample. Usually a sample of 50 or 100 items is taken. The central line is indicated by means of ¼-inch-wide, blue-colored, pressure-sensitive tape. The upper control limit is indicated by a ¼-inch-wide, red-colored, pressure-sensitive tape. Usually this upper limit is established at 2σ to increase the sensitivity of the chart.* (The 3σ limits are so wide for small sample sizes that the chart lacks sensitivity toward shifts in pn.) The board shown has 22 columns to provide hourly samples on three-shift operation

* Statistically, 2σ limits would mean that on the average about one point in 20 would be outside the 2σ limit, even though no assignable cause for variation was present; however, this cost for looking for trouble when no trouble exists is a small cost for increasing the sensitivity to obtain an indication when an assignable cause is present and bringing about a shift in the $\bar{p}n$.

with time out for lunch periods. A permanent record can be obtained by placing a paper form between the aluminum-sheet back and the Plexiglas front. The pegs are punches that perforate the paper.

10.4 SIZE OF SAMPLE

For $\bar{X},R$ charts, samples should preferably consist of a subgroup of 4, 5, or 6 items. Subgroup size of 2 or 3 results in lack of sensitivity for the $\bar{X}$ chart. Subgroup size of over 10 results in loss of efficiency for R in giving a measure of the standard deviation. A series of 25 subgroups should be used for calculation of trial control limits and central lines (see Section 13). Limits should be reviewed at the end of each run of 25 subgroups and adjusted until standard values for average and range can be established. Even after standard values are established, periodic review of the process against the standard should be made.

For p, pn, and c charts, the samples should be large enough to provide 3σ control limits that have a reasonable degree of sensitivity. Crawford and Howell * have recommended that the upper limit should not be more than three times the value of the average. By equating UCL to $3\bar{p}$, they derive the formula

$$N = \frac{2.25}{p}$$

where N = sample size
p = average fraction defective

Juran† derives another formula based on the criterion that the presence of no defects in the sample will indicate a significant improvement over standard, i.e., $p = 3\sigma_{\bar{p}}$.

* James R. Crawford and John M. Howell, *Engineering Statistics of Quality Control*, 1944, University of California War Training ESMWT 541.

† Juran, *Quality Control Handbook*, p. 394.

10.5 METHOD OF TAKING SAMPLES

Samples should be taken to obtain rational subgroups. A rational subgroup is defined as a group *within* which variations may for engineering reasons be considered to be due to nonassignable chance causes only, but *between* which there may be differences due to assignable causes whose presence is considered possible. All members of a subgroup should be produced under essentially the same conditions; hence items comprising the subgroup should be taken from a very short interval of time. For example, it would be preferable to take a sample from the product made during a five-minute interval rather than taking it at random from the product accumulated over an hour's time. (If sampling is done for acceptance purposes, rather than for control chart purposes, a random sample taken from several hours' production is desirable in order to represent all periods of production. See Acceptance Sampling, Art. 11.)

10.6 FREQUENCY OF SAMPLE

The frequency of sample depends on the period of time one would be willing to operate the process "out of control" without being aware that it was out of control. Economic considerations usually influence the decision. For example, if a sample showed the process to be out of control, it might be desirable to screen all the product made after the preceding sample that indicated that the process was in control.

Where very close control is desired, samples may be taken as frequently as every 15 minutes. Common practice is to sample approximately once each hour. For processes that have remained in good to excellent control over long periods of time, a sample taken once every four hours or once a shift should prove adequate.

10.7 WHO SHOULD KEEP THE CONTROL CHART?

When a control chart is started, it is usual for a quality control engineer or quality control analyst to obtain the initial measurements, calculate control limits, and set up the chart. Also, any later revision of limits is the responsibility of such persons.

Once the chart is established, either the operator or inspector on the job may obtain the measurements, make the simple calculations involved, and plot the points. If the type of operation permits, it is preferable to have the operator run his own chart. He is more likely to feel that the chart is a tool to help him control the process rather than a device that gives the inspector a way of checking on him. Some object that the operator would be tempted to bias the results to make a good showing on the chart. An occasional audit point identified by the foreman or inspector would reveal such bias if you really think the operator would "cheat."

Another objection is that the operator is hired to manufacture, not "to keep books." But a little "paper work" might add to the interest of the job. Actually, to add five figures, get an average, subtract the smallest figure from the largest in a subgroup, and plot a point on the $\bar{X}$ chart and another on the R chart should take about two minutes. By using subgroups of five, division can be accomplished by doubling the total for the subgroup and pointing off one place. Division could be eliminated entirely by setting up control limits on the total instead of the average. In the opinion of some quality control engineers, this procedure has the advantage of giving a number that does not resemble the specified measurement; hence it eliminates possible confusion between the values for averages and for individual measurements.

In the case of *pn* charts, the punch board can easily be kept by the operator —even if he has oily hands! (See Art. 10.3.)

10.8 HOW MANY CONTROL CHARTS?

Obviously, running a chart on every characteristic of every part and product would be nonsense. Charts should be run only on important characteristics and then only if they will "pay their way." It costs money to provide and maintain test equipment, obtain measurements, calculate results, and plot and interpret charts. If the chart saves more than these costs, then it should be kept. If not, it should be eliminated. If a chart is not quite paying its way, it is often advisable to decrease the frequency of sampling to reduce costs rather than lose entirely the values the chart provides.

10.9 PROCESS CONTROL ACTION

Process control procedure may be divided into four principal steps:

1. Decide what characteristics are to be controlled.
2. Get the facts. Determine the process "pattern" by measuring the product for characteristic under consideration.
3. Analyze the data by means of process capability studies and statistical quality control charts.
4. Take necessary corrective action.

Table 14.2 gives a schematic diagram of action to be taken depending on process performance versus specification.

11. ACCEPTANCE SAMPLING

11.1 PURPOSE OF ACCEPTANCE SAMPLING

The purpose of acceptance sampling is to arrive at a decision with regard to acceptance or rejection of a lot, without having to examine the entire lot. Inspection economy is thereby afforded.

Acceptance sampling may be used at three different stages of the process:

1. Lot-by-lot acceptance of purchased (incoming) materials.

TABLE 14.2 ACTION TO BE TAKEN UNDER CERTAIN CONDITIONS OF CONTROL AND TOLERANCE

PROCESS		PRODUCT	
Stability	"Spread" with relation to tolerance*	Meets tolerance	Does not meet tolerance
In Control	Variation Large →	No action.	Process may be misset and also have too much spread. Reset and consider economics of wider tolerances vs. precision process vs. sorting.
	Variation Small →	Possible cost reduction through less precision in process. Widen tolerances if sound from engineering standpoint.	Process misset. Reset at proper average. Correction can usually be achieved without difficulty.
Out of Control	Variation Large →	Determine cause and eliminate if economically justified.	Process is misset, erratic, or both. Determine cause for lack of control. Consider economies of wider tolerances vs. precision process vs. sorting.
	Variation Small →	No action.†	

* "Spread" of process considered to be small with relation to tolerance if it is one-third or less that of the total tolerance; large if over two-thirds total tolerance.

† Even in this case it is advisable to identify the cause for lack of control so that it can be "held in check." An out-of-control process is unpredictable and may run for periods where the product does not meet tolerance.

2. Acceptance of material moving from one manufacturing section to another within the factory.

3. Acceptance of completed product for shipment to the consumer.

11.2 TYPES OF ACCEPTANCE SAMPLING

1. Attribute. Where acceptance criteria are based on the number of defectives or defects found in the sample.

2. Variable. Where acceptance criteria are based on "mean" and "spread" of a number of individual *measurements* on articles making up the sample.

11.3 ACCEPTANCE SAMPLING PLANS

Various sampling plans and their characteristics have been discussed in Section 13, Industrial Statistics. A plan specifies a sample size for a given lot size and the acceptance criteria, i.e., number of permissible defects in the sample. Each sampling plan has stated risks. It is important that the quality control engineer be thoroughly familiar with the operating characteristics of the plan he is using so that he will know the producer and consumer risks involved. It should be emphasized that the AOQ (Average Outgoing Quality) given by a sampling plan is a *long-term average*. Individual lots may be accepted which have a per cent defective considerably above this average, depending on the quality submitted. The OC curve (Operating Characteristic curve) gives this information.

Single, double, or multiple sampling plans (see Section 13, Art. 3) may be selected to give either:

1. Lot quality protection.

2. Average outgoing quality protection.

The former, LTPD or p_t (Lot Tolerance Per cent Defective) corresponds to $P_a = 0.10$ on the OC curve for most

commercial applications. A considerable amount of inspection (large samples) are necessary to insure a low p_t.

Average quality or average outgoing quality limit (AOQL) is generally the basis on which sampling plans are selected, for it is the *average* that is most generally dealt with from a cost standpoint.

11.4 SELECTION OF PLAN: SINGLE, DOUBLE, OR MULTIPLE

After it has been decided whether inspection is to be on an attribute or variables basis, and after a decision has been made between lot quality protection and average quality protection, there is still a decision as to single, double, or multiple sampling when attribute inspection is used.

Single sampling is the most easily administered and the least complicated as far as procurement of samples is concerned; however, where inspection cost per unit is high, the smaller amount of sampling afforded by double and multiple sampling is an offsetting advantage. Single sampling gives the most information on the quality level of the lot.

When submitted quality is better than the AQL for the plan (as it usually should be), double and multiple sampling require a lower average amount of inspection than single sampling. When AQL values are so low as to require two and three multiple samples before acceptance, this advantage for multiple sampling decreases in importance.

Double and multiple sampling have a psychological advantage in that they afford the producer a "second chance."

When submitted quality is considerably worse than the AQL, double and multiple sampling require less average inspection due to rejection on the first sample.

When quality is intermediate, double and multiple sampling may require more inspection than single sampling.

When double sampling is used, care should be taken that the persons who use the tables understand that the *second acceptance number is the number of permissible defects in the combined first and second sample* and does not apply to the second sample alone.

11.5 IMPORTANCE OF PROCESS AVERAGE

In selecting sampling plans, it should be recognized that single sampling gives the most information concerning the process average that provides a basis for decision between normal, tightened, and reduced inspection (see Section 13, Art. 3.83).*

Because of the importance of the process average, the specified first sample should be completed regardless of what plan was chosen and regardless of the fact that the rejection number may be reached prior to completion of inspection for the first sample. The percentage of defectives found in the first sample provides a measure or estimate of the process average. In double sampling plans, inspection may be terminated as soon as the rejection number is reached *during the inspection of the second sample*. In multiple sampling, inspection may be terminated during the second or beyond the second sample.

A suitable record card should be provided which will tabulate inspection results on first samples. Figure 14.6, page 979, shows such a record form.

11.6 TIGHTENED INSPECTION

Tightened inspection provides protection against acceptance over an extended period of lots that have quality slightly worse than the acceptable quality level (AQL). The tightened inspection reduces the probability of accepting a lot of a given fraction defective and is used when it becomes apparent that below-standard quality is being submitted (see Section 13, Art. 3.83).

* For a more complete discussion of selection of sampling plans, see Grant, *Statistical Quality Control*, 2nd ed., pp. 384-387.

11.7 REDUCED INSPECTION

(See Section 13, Art. 3.83.) Reduced inspection is optional. Unless its use will actually permit a reduction in inspection force or permit the "fixed" inspection force to devote more time to closer inspection of critical characteristics, it should not be used. Where a large number of items may qualify for reduced inspection, real economy may be realized and the inspection force may be reduced. It must be realized, however, that protection against an occasional bad lot has been greatly reduced through the use of reduced inspection.

11.8 FORMATION OF INSPECTION LOTS

The more homogeneous the lot being sampled, the better chance that the sample will properly evaluate the lot. For this reason, it is advantageous to have the vendor or producer keep separate those articles that are produced under essentially the same conditions. If the product from one machine could be considered as a lot and sampled as a lot, it would be better than making up a lot of product from two or more machines. To do this requires a close working relationship with the vendor (see Art. 12.3).

Subject to the foregoing limitations, inspection lots should be as large as possible. The large inspection lot calls for larger samples, which permit better discrimination between good lots and bad. Also, the sample specified for large lots is a smaller percentage of the total items submitted than is the case with smaller lots.

11.9 RANDOMNESS IN SAMPLING

All sampling plans are based on the sample's being selected in a random manner—i.e., all pieces in the lot have an equal chance of being selected to make up the sample. The calculated risks, quality limits, and so on, are likely to be in error unless the sample is a random sample.

This is one of the most important requirements in acceptance sampling, yet it is the one most often neglected. It takes discipline and effort to get a random sample. The inspection supervisor must provide means for shifting pallets and opening crates to insure a random sample.* A good disciplinary device is the use of a table of random numbers for selecting pre-numbered articles from the lot.

A "sampling thief," such as that used in the milling industry for sampling grain, is a useful device for sampling kegs of small rivets, nuts, bolts, screws, and so forth.

11.10 PROBLEM OF RESUBMITTED LOTS

Lots that have been rejected, returned to the producer for 100 per cent inspection, and resubmitted to the consumer's acceptance sampling should be properly identified so that:

1. Results of inspection on 100 per cent detailed lots will not be included in process average calculations.

2. More severe acceptance criteria may be used to assure that practically all the defectives were removed. (This is a requirement if the AOQL of the plan is to be relied upon.)

A special problem arises if rejected lots are resubmitted unchanged, without any detailed inspection, on the chance that they will be accepted on the next sampling inspection. The only protection the consumer has is to insist upon proper identification of resubmitted lots. This is a requirement in MIL-STD 105A, used for government procurement.

11.11 ACCEPTANCE SAMPLING BY VARIABLES

Although acceptance sampling by attributes has more widespread use, because of its simplicity, than acceptance sampling by variables, the

* The problem of how many containers should be opened is discussed in Juran, *Quality Control Handbook*, pp. 421 and 422, footnote.

latter will fill a specific need where it is important to *measure* certain specific quality characteristics.

Acceptance sampling by variables has the following advantages over attribute sampling, as given by Grant:*

1. Better quality protection with a small sample size.
2. Measures degree or extent of conformance or nonconformance.
3. Better basis for guidance toward quality improvement.
4. Better basis for giving weight to quality history in acceptance decisions.
5. Errors of measurement more likely to be disclosed by variables information.

Plans for acceptance sampling by variables are explained in Section 13, Arts. 3.10 to 3.15. Although the calculations based on the sample measurements are not particularly complicated, they are generally more difficult than would be undertaken by the average inspector or inspection supervisor. It would be up to a quality control engineer or statistician to process the inspection results and reach the decision to accept or reject. Such a procedure offers limitations in industry.

A plan that makes use of a frequency distribution of a sample of 50 measurements is the Lot Plot Plan developed by Shainin. This plan can be operated by the inspector of above-average intelligence and is being successfully used by many companies. A set of concise rules are given, involving calculation of 3σ from $\bar{R}$ based on 10 subgroups of 5 measurements each and $\bar{\bar{X}}$.†

12. VENDOR RELATIONSHIPS

12.1 FACTORS INVOLVED IN CONSUMER-VENDOR RELATIONSHIP

Amicable relations depend on *understanding and agreement* on price, delivery, and quality requirements. Too often the last item, quality requirements, has not been clearly defined and agreed upon. *Quality requirements should be made a part of the contract agreement.*

* Grant, *Statistical Quality Control,* 2nd ed., p. 408.

† For a complete presentation of this plan, see Dorian Shainin, "The Hamilton Standard Lot Plot Method of Acceptance Sampling by Variables," *Industrial Quality Control,* Vol. 7, No. 1. July 1950, 15-34.

12.2. OBJECTIVES OF A VENDOR-CONSUMER QUALITY PROGRAM

1. Cost reduction.
2. Improved delivery.
3. Acceptable product.
4. Rapid correction of process.
5. Over-all economy of inspection.
6. Agreement on disposition of nonconforming product.
7. Mutual confidence.

12.3 COMPONENTS OF A VENDOR-CONSUMER QUALITY PROGRAM

1. Clearly define quality requirements on a realistic basis. Classify quality characteristics as to importance, and state the AQL (Acceptable Quality Level) for each important characteristic. Figure 14.14 shows a form that sets forth this information; this form becomes a part of the purchase order.

2. Aid the vendor in establishing effective quality control techniques for process control in the vendor's plant (see Art. 10).

3. The vendor, in turn, furnishes the consumer with process average information as a part of the quality certification (see Item 6 below).

4. Vendor and consumer agree and standardize on gaging and testing methods, and inspection procedures and standards, including sampling plans.

5. Vendor agrees to "lotting" product so that one lot of product will include parts that have been produced under essentially the same conditions. This procedure will facilitate later sampling by the consumer—and, in case of difficulty, will facilitate segregation of non-conforming lots.

6. Vendor provides consumer with a *Certification of Quality,* which will convey the vendor's test results, along

FORM L-9240 (3-50)

PART NAME Riser Tube DWG. NO. K-5426119 REV. 3

QUALITY CONTROL INSPECTION PLAN Mod. G. E. Per S. I. Sec. [illegible]

Elec. Housewares Dept. GENERAL ELECTRIC COMPANY Ontario WORKS

Issued By: S. L. Callaway Supersedes: 10-8-52 Effect. Date: 1-27-53

CHARACTERISTICS AND ACCEPTABLE QUALITY LEVELS (AQL)

ITEM NO.	TEST REQUIREMENTS	CODE	CRITICAL CHARACTERISTICS	AQL	MAJOR CHARACTERISTICS	AQL
1	Leak Test 2 psi air	½%				
2			.632 Diam. hole	2%		
3			.900	1%		
4			.073	1%		
5			.880	2%		
6			.727	2%		
7			.632 diam. hole center	1%		
8			Top edge in plane	1%		
9					.916 Dia.	3%
10					1.390	5%
11					.050 Max.	3%
12					9/16" Diam. hole	3%
13					.020 wall thickness	3%
14					63/64" Dia.	3%

Code letters for test and AQL's are for G.E. internal use only.

All parts should be to drawing specification in all respects. The most important characteristics to be checked with their Acceptable Quality Levels are listed above. Inspection by G. E. Company may be made by recognized sampling methods. Lots exceeding the AQL per cent defective as indicated by the sample inspection will be rejected and returned to the vendor or, if necessary to maintain production, will be sorted or reworked at the vendor's expense. The requirements of this Inspection Plan are a part of each purchase order.

Courtesy General Electric Company.

FIG. 14.14 QUALITY CONTROL INSPECTION PLAN.

with the respective product, to the consumer. The objective is to eliminate unnecessary duplication of inspection and testing on the part of the consumer. (The consumer may make occasional check tests to confirm the vendor's results.)

7. The consumer accepts the vendor's product on the basis of a mutually acceptable sampling plan, such as MIL-STD 105A for Attribute Sampling (Section 13) or the Lot-Plot Plan for variables sampling (Art. 11.11 of this Section).

8. The consumer "feeds back" the results of his inspection to the vendor so that the vendor can see if test results are in agreement.

9. Procedures are established with regard to handling and financial responsibility in the event that a lot received by the consumer fails to pass acceptance criteria; i.e., lot to be returned to vendor for sorting and/or correction, lot to be sorted by consumer at vendor's expense, or other arrangements.

10. Consumer agrees to absorb loss on few defective articles that are present in acceptable lots.

11. Vendor informs consumer of any necessary changes in process or substitution of materials so that consumer can make tests and take proper precautions.

12.4 THE CONSUMER'S BUYER DEALS WITH THE VENDOR

All dealings with a given vendor should clear through one individual in the organization, usually a member of the purchasing section. The quality control engineer should work through the buyer in making contacts with the vendor.

12.5 VENDORS' RATINGS FOR USE OF BUYER

Vendors are individually rated on the basis of the ratio or percentage of lots accepted to total lots received. According to their quarterly percentage rating, vendors may be classified as preferred, acceptable, probational, or not approved.

12.6 INSPECTION OF VENDOR'S FACILITIES BY CONSUMER

When a new vendor is being considered, it is advisable for the buyer to arrange an inspection of the vendor's facilities by the consumer's quality control engineer or other representative to be assured of the adequacy of the vendor's facilities to produce to the consumer's requirements.

It also proves helpful to return the favor of a visit by having the vendor come into the consumer's plant so that the vendor can see where the part goes, what is required of it, and how it is tested.

12.7 VENDOR PRODUCT QUALITY CONFERENCES

Some large companies, who have several hundred vendors, have used vendor conferences to good advantage. All vendors are invited to send one or two representatives to a formal, but varied, one-day program at the consumer's plant. Aims and objectives of the quality control program are presented. A luncheon and plant visit are included. Such programs have been well received by suppliers.

12.8 USE OF PAMPHLETS OR BROCHURES IN VENDOR-CONSUMER RELATIONSHIPS

Some large companies* have published a series of pamphlets outlining vendor-consumer objectives and plans.

On the other hand, some vendors through their associations† have published pamphlets setting forth their limitations, extra costs for certain requirements, standard finish to be expected, and so forth.

Such brochures and pamphlets provide an excellent medium through which vendor and consumer can understand each other's problems and reach their common goal of high quality at low cost.

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* "Quality Level Certification," Ford Motor Co., Dearborn, Michigan, 1951.

† "Buyers' Guide for Screw Machine Products," National Screw Machine Products Assoc., 13210 Shaker Square, Cleveland 20, Ohio, 1945.

13. QUALITY AUDIT

13.1 MEANING OF THE TERM "QUALITY AUDIT"

The term "quality audit" has been used to mean several different things. Without exception, it is considered a part of the *quality assurance* function. Juran* uses the term to mean a periodic quality survey of all quality factors for a given product. McNairy,† Small,‡ and others have used the term "quality audit" to mean "An engineering check on the quality of product ready for shipment." This is what Juran calls a "quality rating of outgoing product" or "check inspection."

Whether the term is used in the broad or the restricted sense, the importance of evaluating product quality from the standpoint of the customer is rapidly becoming appreciated in industry.

13.2 ACTUAL-USE TESTS

The quality audit includes some tests not necessarily used in factory inspection and test activity. *Actual-use tests* might not be practical on the factory test line, but certainly the quality audit should include tests to see, for example, if a mixer really mixes heavy cake batter, a washing machine washes delicate garments, or an automobile endures under severe road conditions. Endurance or life tests are considered a part of the quality audit testing program. Life tests are discussed separately in Section 14.

13.3 A QUALITY RATING PLAN FOR THE QUALITY AUDIT

In order to evaluate the quality of the product for successive periods of manufacture, various rating plans have been devised. Of course, the conventional control charts prove useful in this regard; however, such charts are usually supplemented by a rating system that makes use of a schedule of demerits for each type of defect found in the finished product. Each article of product examined is given a rating. In one system, which has been used in the electrical appliance industry, an item devoid of defects would have a rating of 100 points. A defect of major importance might carry 30 demerits. An item with such a defect would have a rating of 70. Since the system is set up with limitations for certain categories of defects, it will not be possible to have an item with a rating below zero. A check list for such a rating plan is shown in Table 14.3.

The number of demerits given to the defect is based on the seriousness of the defect. Various systems are in use that classify defects as to their seriousness—i.e., critical, major, minor A, and minor B.

Various ratios of weights are arbitrarily given to the various classes of defects. A fourfold system might have 100, 50, 10, 1, or 20, 15, 5, 1. A threefold system could be in the ratio 10, 3, 1. A twofold system (i.e., major and minor) could be 3, 1.

With any such system given, and with demerits assigned to all defects encountered, it is possible to rate each unit of product either in terms of demerits per unit or rating (100 points minus demerit points) per unit. It is then possible to calculate the average rating of the sample for a period such as a week or a month. This procedure gives very valuable information of a type that can be charted and presented to management. Limit lines* on such a chart are useful in telling management when the product quality has significantly declined or improved with reference to a base period. Such information provides the executive with a basis for action.

* *Quality Control Handbook*, p. 334.

† J. W. McNairy, "An Appraisal of Quality Control," *Industrial Quality Control*, Vol VI, No. 1, July 1949, 5-14.

‡ Bonnie B. Small, "Use of Control Chart Techniques in Making a Quality Audit," *Industrial Quality Control*, Vol. VI, No. 1, July 1949, 15-19 and Vol. VI, No. 2, September 1949, 11-15.

* Juran, *Quality Control Handbook*, pp. 332, 333.

TABLE 14.3 CHECK LIST FOR RATING PLAN*

(Quality control—Automatic washer)

I. Operational Defects		40%
A. Mechanism:		
1. Agitate power	5.00	
2. Start spin power	8.00	
3. Full spin power	5.00	
4. Torque	3.00	
5. Resistances (each)	2.00	
B. Tub and apron assembly		
1. Loose screws in tub flange	0.25	
2. Suds kill baffle screws loose	0.50	
3. Suds kill baffle lock washers missing	0.50	
4. Suds kill baffle screws corroded	1.00	
5. Suds kill baffle screws stripped		
C. Dole valve:		
1. Water-temperature control (each)	10.00	
2. Flow control	3.00	
3. Inoperative	25.00	
4. Noisy	5.00	
5. Poor shutoff	25.00	
D. Circulating and drain pumps (demerit each pump):		
1. Noisy motor	3.00	
2. Inoperative	30.00	
3. Loose through bolts	3.00	
4. Defective motor leads	1.00	
5. Lead through housing and adapter	2.00	
II. Appearance Defects Other Than Paint		20%
A. Cover assembly:		
1. Dented	3.00	
2. Trim band not tight	2.00	
3. Trim band wrinkled	2.00	
4. Trim band burred	2.00	
5. Trim band poorly finished	3.00	
B. Apron and back panel:		
1. Wrinkled	1.00	
2. Dented	3.00	
3. Poor fit with cover	3.00	
C. Controls:		
1. Not horizontal	2.00	
2. Poor lettering on dials (each)	0.50	
3. Discolored dials	1.00	
III. Crating		20%
1. Suspension blocks loose	5.00	
2. Crate bottom loose	5.00	
3. Old-style crate	20.00	
4. Nails missing	0.50	
5. Nails mislocated	0.25	
IV. Condition of Paint		20%
1. Orangepeel	3.00	
2. Rough paint	3.00	
3. Too thin	3.00	
		100%

* Reproduced by Permission of *Industrial Quality Control*. "An Appraisal of Quality Control" by J. W. McNairy in Vol. VI, No. 1 of *Industrial Quality Control*.

14. LIFE TESTS

14.1 LIFE: A QUALITY CHARACTERISTIC

The life of a product is but one of several quality characteristics; however, it receives special consideration over other quality characteristics because of:

1. Elapsed time to evaluate.
2. Destructive nature of test.

A life test seeks to measure the *time or period during which the product will retain its desired quality characteristics.* This may apply to either or both (1) shelf life and (2) life during use.

Many expendable products, which have no life in use, i.e., food products, do have considerable importance attached to their keeping qualities or shelf life. On the other hand, an electric lamp may present no problem as far as shelf life is concerned, but its life in use becomes an important factor.

14.2 LIFE TESTS: ACTUAL-USE CONDITIONS

One method to evaluate the life of a product is to identify the time it went into regular service and the time it finally failed in regular service. Some products may be in actual service use only a few hours a week. Usually this is such a time-consuming procedure that it is of little value for control of a manufacturing process. It is important, however, to run a limited number of actual-use tests to determine how intensive life test results or accelerated life test results correlate with actual life in use.

14.3 LIFE TESTS: INTENSIVE CONDITIONS

A test under intensive conditions differs from a test under actual-use conditions in that *idle time is eliminated* to hasten the test results. For example, the electric hand iron is used approximately three hours per week in the average home. In an intensive life test on an electric hand iron, the iron would be operated continuously at rated voltage (except for an occasional cool-down period to reveal any weaknesses due to alternate thermal expansion and contraction). In this way, the results can be obtained in a few months instead of several years.

14.4 LIFE TESTS: ACCELERATED CONDITIONS

Under accelerated conditions, the device is operated under severe conditions to hasten its breakdown, i.e., high speeds, high voltages, high temperatures, severe vibration, abrasion. For example, the electric hand iron might be operated at 150 volts instead of 115 volts in order to burn out the heating element sooner. Accelerated life tests are of value only to the degree with which they correlate with actual-use life tests or intensive life tests (see Correlation, Section 13, Art. 5.7).

There is a definite limit to severity of conditions. Beyond this limit other factors, quite different from those encountered in actual use, enter to give misleading and false evaluation of life.

14.5 LIFE TEST: STATISTICAL ANALYSIS OF DATA

There are two requirements for life testing:

1. Small samples (because of destructive nature of test).
2. Prompt test results.

These requirements place great importance on powerful statistical techniques. Here is a very fertile field for some signal contributions by statisticians.

The Shewhart Control Chart has proved a powerful technique in the field of destructive testing where samples are limited by economic considerations (see Section 13). Life testing is a special application of this procedure; however, certain modifications can be made

TABLE 14.4 SAMPLE SIZE REQUIRED IN A LIFE TEST*

The sample size required in a life test to be sure (with probability $P\%$) that fewer than $k\%$ of future units will fail in a time shorter than the shortest life in the sample.

$k\%$ \ P in %	99.9	99	95	75	50
0.1	6977	4652	3026	1401	701
1	689	459	299	139	70
2	343	229	149	69	35
3	227	152	99	46	23
4	170	113	74	34	17
5	135	90	59	28	14
10	66	44	29	14	7
15	43	29	19	9	5
20	31	21	14	7	4
25	25	17	11	5	3
30	20	13	9	4	2
35	16	11	7	4	2
40	14	10	6	3	2
45	12	8	6	3	2
50	10	7	5	2	1

* Reproduced by permission from Dr. J. H. Davidson, "Statistical Methods in Industry," *General Electric Review*, September 1952.

to save time in making conclusions on test results. Purcell* has established control charts on the median and the minima in testing electric lamps. With this technique, it is not necessary to run the entire sample to destruction. Conclusions can be drawn on the time of the first failure and median or middle failure. Other statistical techniques have been developed to economize on time in evaluation of life test data. Davies† has installed a system for evaluating radio tube life. Another method of rating life of radio tubes has been presented in Juran's *Quality Control Handbook* by members of Sylvania Electric Products, Inc.

A very useful statistical aid in planning life tests is shown in Table 14.4. This table was developed by Dr. J. H. Davidson and is reproduced here by permission of the General Electric Review. The table shows the sample size required in a life test to be sure (with probability P per cent) that fewer than k per cent of future units will fail in a time shorter than the shortest life in the sample.

For example, if we wanted to be sure to probability 95 per cent that not more than 5 per cent of the product would fail before 2500 hours, we would have to life-test 59 items and have all items run 2500 hours before the first failure occurred.

* Warren B. Purcell, "Saving Time in Testing Life," *Industrial Quality Control*, Vol. III, No. 5, March 1947, 15-18.

† J. Alfred Davies, "Life Test Predictions by Statistical Methods to Expedite Radio Tube Shipments," *Industrial Quality Control*, Vol. IV, No. 1, July 1947, 12-17.

15. PACKAGING

15.1 DELIVERED QUALITY

Unless the product is delivered to the customer in a satisfactory condition, the quality job has not been carried to completion. The product may be perfect when it leaves the factory; but if it is received by the customer in a damaged condition, much customer dissatisfaction and monetary loss may result.

15.2 SPECIAL PROTECTION REQUIREMENTS

The nature of the product may require special protection from the following deteriorating factors: elevated temperatures, freezing or sub-zero temperatures, sudden changes in temperature, humidity (high or low), sunlight, dust, micro-organisms, air (oxygen), vibration, shock, abrasion (from packing materials), water damage, absorption of off-odors or off-flavors, and many other factors. Through special packaging and handling, it is possible to protect the product from any or all of these factors. Such protection may involve hermetically sealed packages, refrigeration, desiccation, grease or plastic coatings, special wrappings, and floating packages. The job of the package engineer is to specify the proper protection and package for a particular product, but it is often the responsibility of the quality control engineer to prove the adequacy of such protection.

15.3 PACKAGING TESTS

Packaging tests may be classified as follows:

1. Tests on the material of containers, such as the Mullen or Cady Tests.*

2. Tests on the packaged product to measure adequacy of package to protect product against handling or in-transit damage due to impact. Such tests would include the drop test, compression, vibration, and revolving drum tests, and the Conbur Test.†

3. Actual trial shipping test with examination of product at destination.

All three types of test have their purpose and should be used. Tests on the quality characteristics of packaging material should be run for quality control purposes just as for any other purchased item.

Carefully controlled tests, such as the second type, offer an advantage of comparing different packages under severe, yet controlled, conditions. This comparison overcomes a serious drawback to the third type, where it is difficult to assure the same handling for various trial shipments and difficult to assure that representative severity of handling was present during the respective trial shipments.

Since it is not always possible to duplicate actual conditions in laboratory tests, it is advisable to have the added protection of actual shipping tests. These tests should duplicate the mode of transportation and distances that will be encountered in getting the finished product to the customer. Special attention should be given to scuffing of highly finished surfaces caused by rubbing (abrasion) of packaging materials on the product.

16. SALVAGE

16.1 SALVAGE ACTIVITY

In the broadest use of the term "salvage," reference is made to the saving, reconditioning, and re-use of all materials found in the factory. It includes, besides spoiled piece parts, such items as: cutting tools, oils, metal chips, and solvent. Although in some establish-

* Standard procedure for making these tests can be procured from the American Society for Testing Materials.

† The Conbur Incline Testing Device is described in *Bulletin No. 511* of the Freight Loading and Container Bureau of the Association of American Railroads, 59 East Van Buren Street, Chicago 5, Ill. The Freight Loading and Container Bureau also provides many pamphlets covering the packaging of a variety of articles of commerce. They also maintain a Container Research and Development Laboratory in Chicago to aid industry in eliminating the causes for loss and damage due to faulty shipping practices. The American Management Association, 330 West 42nd St., New York 18, N. Y., has also published a Packaging Series of pamphlets which are helpful in analyzing and solving packaging problems. Series No. 32, "How General Electric Tackles Its Packing and Shipping Problems," and Series No. 34, "Protecting the Package In Transit."

ments this broad activity* is centered in a separate salvage department, quite often salvage of piece parts or products falls to the lot of the inspection department.

16.2 SALVAGE CAGE OR CRIB

It is important to have a separate area physically removed from production and assembly areas, in which non-conforming product can be stored until it can be reviewed by the salvage committee (see Fig. 14.4) for disposition and until final disposition can be put in effect. This precaution is extremely important to avoid mixture with the good stream of production parts. It is preferable to have the area locked so that overzealous production expediters will not "rob" salvage for "badly needed parts."

16.3 SALVAGE COMMITTEE OR MATERIALS REVIEW

The salvage committee† reviews rejected material and decides on disposition, i.e., accept on deviation, rework, or scrap. It usually specifies how the work is to be accomplished when rework is applicable.

16.4 SALVAGE RECORDS

A record of salvage committee action should be made to serve as authority to deviate from specification. (The engineering section representative's decision is tantamount to a deviation.)

Regular paper work in the form of scrap and rework tags (see Art. 8.1) should be attached to all work entering the salvage section and should be completed before leaving the section for final disposition.

16.5 BASIS FOR DECISION

Safety and quality reputation are of primary importance in all decisions.

The basic considerations should be economic. In other words, rework costs should not exceed the value of the part —unless, of course, availability is a primary consideration. In such a case, the cost of rework would be balanced against the cost of a shut-down.

In cases of mixed parts or bad parts mixed with good, segregation of good from bad is permissible without formal salvage committee action. Final disposition of bad parts sorted out should be made by the salvage committee.

17. FIELD RESULTS

17.1 FIELD RESULTS AS A MEASURE OF QUALITY PERFORMANCE

Since customer satisfaction is an important goal of the quality control program, it is highly desirable to obtain some measure of it and thereby to measure the effectiveness of the quality control program. Customer complaints give a measure of *dissatisfaction*, an inverse measure of satisfaction.

Caution must be exercised in using the complaint rate as a quality index, since other factors are involved, such as market conditions, inventories, styles, and general attitude of the buying public.

17.2 MEASURING THE COMPLAINT RATE

Several different bases may be used, such as:

1. Percentage of total units produced that resulted in complaints. Usually a

* For a thorough treatment of the broad salvage program, see *Salvage Manual for Industry*, War Production Board (Washington, D. C.: Superintendent of Documents, Government Printing Office, September 2, 1943).

† See Fig. 14.4 for salvage committee personnel.

definite warranty period is established on a product. The percentage should be calculated from the ratio of units on which in-warranty complaints were received to the number of units exposed or in use in the field on which the warranty is valid. The latter figure can be obtained from shipments—allowing suitable time lag for the product to get into the hands of the customer. (This time lag has been found to average two to three months for small electrical appliances in an active market.)

2. Ratio of in-warranty expense to manufacturing cost of units exposed in the field. Unfortunately, this index is affected by factors related to product service costs, such as increased labor rates for repairmen, improvement in service through establishment of more and better service repair shops, and increased handling costs due to changes in shipping rates.

3. Service calls (large appliances, etc.) per thousand units sold and on which warranty is still valid.

The chief value in these indices is in showing trends. However, due caution must be used in evaluating extraneous causes for trends as cited above.

17.3 DETERMINATION OF CAUSES FOR COMPLAINTS

This is often a difficult task. In fact, it is often impossible to get a statement on the specific complaint of the customer for small appliances, since the dealer sends the customer's item in with a notation "repair in-warranty." This leaves the complaint a "guess" on the part of the repairman. Even after the complaint has been stated, there may be several possible causes, none of which is clearly defined.

These problems are not as great for major appliances where the repairman goes to the home of the customer and often has the opportunity to interview the customer.

The manager of quality control endeavors to obtain causes for complaint from the repairman through the sales or service organization. The specific information may be a check list or report that the repairman makes on each article returned for repair or replacement. Since a specific defect might be described in several different ways, it is advisable to issue a glossary of terms so that all repairmen will standardize on the description of a defect or cause for complaint. The repairman's report should also include date of manufacture (date code), date of sale, date of repair, serial number, if so numbered, operating conditions, and any other information that would help to trace the cause for the complaint.

Sometimes it is too expensive to process all reports from the field. In such cases, a sample may be taken or only certain districts may be requested to report. Care should be taken in such cases to avoid a biased sample caused by differences between districts, such as climate and conditions of use.

Use of replacement parts also gives some information on causes for failure of the device in the field.

Field or service engineers are a valuable source of information.

Complete and sole reliance should not be placed on written reports or check lists from the field. An occasional visit to repair stations or service shops by quality control personnel can be of tremendous value. There is no substitute for a first-hand investigation and analysis of items returned because of complaints. In some instances, the quality control engineer should request that certain examples of complaints be sent to him at the factory for his personal investigation—the size of item permitting.

17.4 USE OF INFORMATION OBTAINED FROM THE FIELD

The only real value of field data lies in the corrective action it initiates. Such action may be improved design, improved test and inspection methods, better packaging, or even a better instruction book. The manager of quality control has a responsibility to see

that the proper people in the manufacturing organization take needed corrective action.

18. PROCESS CAPABILITIES

18.1 MEANING OF PROCESS CAPABILITY

Every process has an inherent variability which can be evaluated by determining its standard deviation (σ') on the basis of a series of individual measurements for the quality characteristic under consideration (see Section 13 for method of determining σ'). A controlled process can be expected to produce individual articles with measurements spread over a band $6\sigma'$ units wide. For example, if a milling operation had a σ' of 0.0008 inches, the total spread for the process would be 6×0.0008, or 0.0048 inches. We would expect the thickest piece to be approximately 0.005 inches thicker than the thinnest piece. If the process is going to be capable of meeting the specification tolerance, the specified tolerance must be at least as great at $\pm$ 0.0025 inches (a total spread of 0.005 inches), but for practical purposes should be $\pm$ 0.0035 inches (a total spread of 0.007 inches) to allow for variations in set-up and tool wear. A good rule is to have $6\sigma'$ of the process equal two-thirds of the total spread of the specified tolerance.

A process capability study is a determination of the total spread of the process as determined by measuring the product produced under controlled conditions. The process capability is independent of the specification but is determined by the condition of the machine, operator skill, tooling, type of operation, and raw materials used.

18.2 USE OF PROCESS CAPABILITY STUDIES

The process capability or operating accuracy of certain types of machines on certain types of jobs is being determined by many persons throughout industry. After sufficient data are collected, it will be possible to catalog the operating accuracy for certain types of machines on certain jobs. The large job shop could use such catalogued data in scheduling jobs for certain machines depending on the specified tolerances. Such a table for Screw Machine Capabilities is presented by Seder in Juran's *Quality Control Handbook,* Table 2, p. 714.

Machine operating accuracy studies have been used to assure proper maintenance of machines. They have also been used as a basis for equipment replacement programs. The expense of a new, high-cost machine was saved for one company when it was shown that the old machine had operating accuracy to meet specification requirements.

18.3 INSTRUCTIONS FOR PROCESS CAPABILITY STUDY

The standard deviation for the process (σ') may be determined (1) on the basis of a frequency distribution of at least 50 individual measurements or (2) from a range chart (see Art. 10.3, Quality Control Charts for Process Control).

Figures 14.15 and 14.16 show a form used in making process capability studies. Instructions on obtaining and analyzing data are given on the reverse side of the form (Fig. 14.16).

[illegible] rev **MACHINE OPERATION ACCURACY**

Works G.E. Works Date December 1, 1944 Machine No. 2000

Machine (Make, Type, Size) ______

Speed, Feed, Type of Operation ______

Drawing No. 75 000 Dimension Checked Length

Tooling for Dimension ______

Material Steel Operator Williams

(1) Var. from Nominal in Mils (x)	(2) Frequency Tally	(3) Frequency (f)	(4) fx (1) times (3)	(5) fx^2 (1) times (4)
+2.0			+	
+1.9			+	
+1.8			+	
+1.7			+	
+1.6			+	
+1.5			+	
+1.4			+	
+1.3			+	
+1.2			+	
+1.1			+	
+1.0			+	
+0.9			+	
+0.8			+	
+0.7			+	
+0.6			+	
+0.5			+	
+0.4			+	
+0.3	1111	4	+ 1.2	.36
+0.2	~~1111~~ 1	6	+ 1.2	.24
+0.1	~~1111~~ 11	7	+3.1 + .7	.07
-0-	~~1111~~ ~~1111~~ 1	11	-0-	-0-
-0.1	~~1111~~ 111	8	- .8	.08
-0.2	~~1111~~ 11	7	- 1.4	.28
-0.3	~~1111~~	5	- 1.5	.45
-0.4	11	2	- .8	.32
-0.5			-	
-0.6			-	
-0.7			-	
-0.8			-	
-0.9			-	
-1.0			-	
-1.1			-	
-1.2			-	
-1.3			-	
-1.4			-	
-1.5			-	
-1.6			-	
-1.7			-	
-1.8			-	
-1.9			-	
-2.0			-4.5 -	
Totals (Σ)		50	-1.4	1.30

FOR INSTRUCTIONS AND FORMULAS SEE OTHER SIDE

Courtesy General Electric Company.

FIG. **14.15** MACHINE OPERATION ACCURACY FORM (FRONT SIDE).

INSTRUCTIONS

1. Unless otherwise stated, the sample size for these tests will be 50 pieces.
2. Pieces tested should be the first production of the machine after set-up.
3. Dimensions must be checked with an accurate measuring device.
4. Where there are multiple spindles or heads on one machine doing the same operation, pieces from each spindle or head should be kept separate and identified.
5. Any disturbance that affects operation must be recorded, such as change in tool, stock or operator. (Here a new sample will usually be required).
6. There should be a separate check and report for each operation performed by a different tooling on the same machine.

CALCULATION SHEET

Sample Size (n) = Total f = Σf = 50

Average ($\bar{X}$) = $\dfrac{\Sigma fx}{n} = \dfrac{-1.4}{50} = -0.028$ Mils

Standard Deviation (σ) = $\dfrac{1}{n}\sqrt{n\Sigma fx^2 - (\Sigma fx)^2}$

$= \dfrac{1}{50}\sqrt{50(\ 1.80\ ) - (\ -1.4\ )^2}$

$= \dfrac{1}{50}\sqrt{(\ 90.00\ ) - (\ 1.96\ )}$

$= \dfrac{1}{50}\sqrt{(\ 88.04\ )}$

$= \dfrac{1}{50}(\ 9.4\ )$

$= .19$ Mils

Machine Operation Accuracy (OA) $= 6\sigma = 6(\ 0.19\ )$

$= \pm 0.57$ Mils

$= \pm 0.0006$ Inches

REMARKS

Courtesy General Electric Company.

FIG. **14.16** MACHINE OPERATION ACCURACY FORM (REVERSE SIDE).

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A. W. Swan was born in Scotland and received his education at George Watson's Boys' College, Edinburgh, and in Canada, where he studied mechanical engineering and graduated with the degree of Bachelor of Applied Science from the University of Toronto. After working as a production engineer in Canada for a number of years, he returned to England where he continued for a time as a production engineer.

He became interested in statistics and other mathematical techniques after he transferred to engineering market research. From 1939 to 1945 he was in charge of installing quality control programs in the Royal Ordnance Filling Factories and was on loan for the promotion of quality control methods to the Ministry of Production and Ministry of Education. From 1946 to 1951 he was in charge of the newly created Statistical Section at the United Steel Companies, Ltd., Sheffield, carrying out investigations of an operational research character. Since July 1951, he has been in charge of the Operational Research Department at Courtaulds Limited, Coventry.

Mr. Swan has contributed a substantial number of papers on industrial statistics and operations research, among which are "The Work and Organization of a Statistical Department in Heavy Industry," *Journal of the Iron and Steel Institute*, September 1948, "Postwar Developments in Operational Research," *Procedures of the First Seminar in Operations Research, Case Institute of Technology, 1951*, and "Human Relations in Industrial Operational Research," *The Engineer*, July 25, 1952. He is a Fellow of the Royal Statistical Society and a member of the Council, Member American Statistical Association, Member Institute of Mathematical Statistics, Fellow of the American Society for Quality Control, Member of the Operational Research Society, and Associate Member of the Institution of Mechanical Engineers.

SECTION 15

Industrial Operations Research

A. W. Swan

Editors' Foreword to Section 15

The phrase "operations research" is a relatively new one, even though many of the techniques used by operations researchers are not new. The first operations research teams were groups of persons of special competence assigned to study various aspects of military operations during World War II. The successes of these teams in dealing with military problems led to the use of operations research teams in various civilian activities, in the manufacturing industries and elsewhere.

As might be expected in such a new field, there are many different viewpoints regarding the exact coverage of the field. In fact, in reviewing this matter in order to plan an operations research section for this handbook, it seemed to us that there were almost as many different definitions of operations research as there were operations researchers. The differences of viewpoint were particularly evident between persons who had worked chiefly in military operations research and persons who had worked chiefly in industrial operations research.

In solving a number of the military problems, actual situations had been represented by idealized mathematical models and advanced mathematical techniques had been used to obtain an optimum solution. There seemed to us to be a tendency on the part of some military operations researchers to insist that the mathematical model was the essential

element in operations research. We believe this viewpoint is unduly narrow, when considered in relation to the possible contributions of operations research techniques to industry.

The following section is oriented entirely toward industry; no attempt has been made to describe military applications or to discuss analytical techniques that have been useful chiefly in dealing with military problems. The author of the section, Mr. A. W. Swan, is an international authority on industrial operations research who has headed operations research groups in two large companies in different industries. The section includes brief descriptions of eight actual cases, each prepared by someone who took part in the particular case. Four of these cases deal with British applications and four with applications in the United States.

The cases cover a variety of situations, all fairly closely related to the subject matter of some of the other sections of this industrial engineering handbook. These examples are all fairly simple from the mathematical point of view. This mathematical simplicity is appropriate from the viewpoint of the over-all objectives of this handbook. Other examples using more complicated mathematics may occur in practice, in industry as well as in military situations.

W. G. Ireson
E. L. Grant

1. GENERAL CONCEPTS AND PRINCIPLES OF OPERATIONS RESEARCH

1.1 DEFINITION

A brief and accurate definition of Operations or Operational Research, hereafter called O.R., is, "the application of scientific methods to industrial problems, leading to recommendations that in turn lead to action." O.R. has much in common with what used to be called "scientific management" as developed primarily by Taylor, Gantt, and Gilbreth. It uses, among other techniques, the various techniques developed by scientific management. There are, however, a number of new and additional features, the most important of which are the method of organization and the application to business and works problems of mathematical, statistical, and other scientific methods which have proved beyond question that they produce practical and useful answers. Applications now extend to every sort of managerial activity.

Historically, the term was first used in World War II, when it was applied to the activities of teams of scientists used by the armed forces of Great Britain and the United States to solve—and to solve quickly—very difficult strategical and tactical problems. Noteworthy successes included finding a method that would render the magnetic mine harmless, increasing the efficiency of anti-submarine aerial warfare, and many others that have been described in the scientific journals and elsewhere

One of the special features of wartime O.R. was the successful employment of scientists from fields that would not have seemed very likely to provide suitable men, such as biology. These men achieved outstanding success. Post-war O.R. as applied in industry has continued to teach the same lesson—that it is not necessary to have been in an industry all one's life to solve the problems that beset its management. There is, however, another lesson taught by wartime O.R. that is just as important—namely, that the specialist scientists coming from other fields achieved their successes by working in teams with the sailors, soldiers, and airmen. As a result, every available type of information was pooled and used jointly. The third principal lesson from wartime O.R. was that the team must have free and continuous access to the top level of management so that the team members may really know what management wants and so that they may follow up any recommendations and secure action at the highest level.

1.2 USE OF CASE HISTORIES

In order to show how O.R. works in industry today, a number of case histories have been assembled on the following pages. Although they come from both sides of the Atlantic and from several different industries, and although the methods employed vary from one case history to the next, they do have certain features in common. These features are:

1. Use of a scientific O.R. worker.
2. Use of a team that includes a scientific specialist and works or office representatives.
3. Scientific, unbiased analysis of the problem. The effort to get away from preconceived notions is noticeable in several of the case histories.
4. Use of a variety of practical and theoretical methods in solving the problems. Ingenious mathematical methods are used to produce highly useful results in several cases. In the case history dealing with production control in a steel works, there is an interesting new form of nomograph which, although it is based on a complicated theory, can be used quickly and without difficulty by a clerk who has no knowledge whatever of the principles on which it has been designed. Time and motion studies have been made in other case histories, coupled with mathematical devices which make the information more useful than it would otherwise have been.
5. The provision of recommendations for action by management, following on the results of investigations.
6. The following up of the recommendations, leading to action.

In planning a manufacturing program, management sets out the various methods available, and in each department it uses the simplest and cheapest method. For example, a factory may produce a few fairly simple castings, and a very large number of small machine parts may be made to very fine tolerance limits. In this case, it would be necessary to have only a partly mechanized foundry, but in the machine shop one would find highly elaborate and costly equipment, such as 6-spindle automatic lathes. Although the scientific attitude is always essential, some situations faced by management can be solved by straightforward analysis and the use of well-known techniques, whereas in other more complicated cases much more elaborate and difficult techniques should be used. The writer once had to deal with a problem in steel manufacture that involved 80 factors, for which the methods of solution were difficult and laborious. The problem was successfully attacked, however, and the resulting answer led to the saving of a large sum of money. It is the duty of management not to be frightened or skeptical of even the most advanced techniques, which may involve mathematics of a very complex type. Management must therefore have available, either as permanent staff or on a consulting basis, people who are aware of and can apply current techniques in O.R.

1.3 POLICY MATTERS IN O.R.

Even after management has granted that O.R. has something new and valuable to offer, it still has many questions to ask. Assuming the questions, here are some suggested answers:

1.3.1 Internal or external (consultant) organization. If there are qualified O.R. consultants available, they can be used satisfactorily; two out of the eight case histories that are given below were carried through by consultants. The writer's own preference, however, is for the internal organization, simply because, although the consultant may do an entirely satisfactory single job, the valuable knowledge he has acquired will no longer be available for further use once contact has been broken. An O.R department within a firm, even a one-member department, is an internal consultancy of continuously growing knowledge. One member of the writer's department is stationed at a factory

some 150 miles from his headquarters. His services have become more and more appreciated by the local executives, and any attempt to move him to the head office would be strongly resisted.

1.3.2 Size of an internal O.R. department. The internal O.R. department should be small, at least at first. The departments concerned in the case histories vary from one up to about eight persons, including computers and clerical staff.

1.3.3 To whom the O.R. department should report. The O.R. department should report directly to the very highest level of management (usually, in the case of a factory, to the production chief.) It is not satisfactory for the O.R. department to report to a sub-head or to a personal assistant. In seven of the eight case histories that follow, responsibility is to the president or managing director, and in the eighth to the research and development committee.

1.3.4 Terms of reference. There is no real limit to the possible terms of reference, since O.R. methods are now being applied to every type of business situation. The actual terms of reference will depend on:

1. The type of job envisaged when the O.R. analyst is taken on, or when an O.R. department is set up.
2. The specialist qualifications of the O.R. workers.
3. The existing departmental structure.

In regard to (2), the O.R. man who is an engineer will tend to think of plant layout, traffic problems, and so forth, in terms of time and motion study; the mathematician may be more interested in applying statistical techniques to costs, labor turnover, and the like.

The existing structure is very important. If, for instance, there is no time study department, the O.R. people themselves can tackle any problem that involves time study; if there is a time-study department and a problem arises that calls for this method of treatment, the department's co-operation will be sought and used in the formation of a team. The writer once had an excellent experience with the latter method. The time-study department in an organization was interested in that common problem in the textile industry, machine interference. Briefly, the problem was this: When one operator is tending a group of machines, how can the pauses in machine operation be made to coincide with operator availability? In this case, the O.R. and time-study departments worked together. The O.R. department suggested "snap-reading" time studies, which were carried out by the time-study men. The results were then handed over to be analyzed by the O.R. department.

1.3.5 Qualifications of the O.R. worker. The O.R. analyst must be trained in some technical field. He may be, as the case histories show, an engineer, physicist, mathematician, accountant, or a specialist in some other area. He must be trained in scientific thinking, and he must have sufficient mathematical knowledge to be able to learn current statistical and other advanced mathematical methods. He need not be a specialist in the industry in which he works, but he must be able to acquire sufficient knowledge of that industry to be able to conduct intelligent discussions with its own specialists. If there is to be more than one person in the O.R. department, there should be at least one trained mathematician, since the tendency in O.R. is more and more toward the use of mathematical methods. There should also be one or more technicians who are skilled in the particular industry in which the O.R. department works. In a steel company, for instance, there might be a mathematician and one or more metallurgists. The O.R. worker must be able to get on with his colleagues in the organization in which he works. Since he is a newcomer who is using rather frightening techniques, he has to convince everyone that he is there to help, not to cause trouble, that his techniques are perhaps not so difficult after all, and that they do bring useful results. The case histories give some excellent examples of this attitude.

1.3.6 Origin of jobs. Until management realizes what O.R. can do, most of the jobs will arise as a result of the O.R. worker's questioning of management to discover what problems exist and which ones he can tackle.

Although the O.R. department will have ideas on suitable jobs, they must be discussed with management in a way that leads management to request the department to tackle certain jobs. The O.R. worker must at all times avoid giving the impression that he is teaching people who have been in an industry a long time.

The writer has found that the best and most fruitful requests have come in the course of general exploratory conversations with production and other executives. Actual examples are: "Will you have a look at our rolling mill capacity?" "Can you help us on the rail bank bottleneck?" "Will you try to simplify our material control methods?"

1.3.7 Assessing the job. The first task is to assess the situation. This may or may not be a simple matter, but the correctness of the assessment is absolutely vital. In the case of the rail bank bottleneck, for instance, there were several possible causes: slow delivery from rail straightening, inefficient crane usage, slow inspection, and so forth. It was desirable to examine all these possible factors. However, the overruling factor was the irregular supply of freight cars to take away the rails, and until this trouble was rectified it would be of little avail to study the other factors. Representations were made in the proper quarters; freight-car supply was made adequate; the bottleneck disappeared, and the stock of rails began to drop. It now became possible to make a study of all the other factors. A time and motion study was made of the crane usage that led to improvements in that quarter.

In the case of simplification of material control, the collection of a huge dossier of existing forms yielded very little in the way of deductions, but a week of discussions with individual heads and sub-heads of the departments concerned showed four or five key troubles. It was then possible to plan an improved scheme and to put it into use.

The importance of not allowing preconceived and long-established ideas to bulk too large in the analysis cannot be overemphasized. The reluctance of members of an industry to abandon traditional attitudes has emerged strongly in more than one case history. In one steelworks investigation, for instance, the results ran quite contrary to the established technical views of the open-hearth manager. When, however, a second investigation of the same situation gave the same results, he was compelled to abandon his long-established views and to agree with the new findings.

1.3.8 Planning. O.R. work always calls for hard original thinking, and often for tedious drawing of graphs and laborious calculations. Consequently, it is sensible to plan for maximum efficiency in all these activities.

In the first place, mechanical effort must be reduced to a minimum. An essential piece of equipment is a calculating machine (not merely an adding machine). This may be manual, such as the Brunsviga or Facit, but preferably should be electric, such as the Facit, Friden, Madas, Marchant, or Monroe. Since calculations are certain to involve much squaring and summing of squares, the present-day calculating machine reduces the risk of error, mental fatigue, and wasted time.

If the O.R. department consists of more than two people, the third member should be a computer. O.R. computing work is interesting and can be made more interesting by including her (preferably her) in the general discussions so that she is aware of the reasons for the calculations and the way in which they are to be used. In time the computer may become so well qualified that she can perform as a fully qualified O.R. worker, depending to some extent on the industry in which the department works. Discussions in the shop, which are the lifeblood of O.R., are often carried on with rough-and-ready managers and foremen who pride themselves on their direct speech. The writer once had

to tell a young lady computer, who had become very well qualified in theory, that he would have to find her a job in some other less chivalrous industry. A trial discussion with a melting-shop manager and development engineer, at which she had been present, had been too polite to be of much usefulness. Equality of the sexes had apparently not reached that steel works.

Most O.R. jobs tend to fall into certain well-defined phases: planning, investigating, calculation, and deduction. Of these, calculation may well take the longest time. The employment of one or more computers therefore makes for over-all efficiency, since the investigator can hand over his data as soon as they are available and then be free to take on another job. It is sound practice for each investigator in an O.R. department to have two or three jobs running at one time, so that the investigation of one can proceed simultaneously with the calculation of another. This system makes it possible for the investigator and the computer to maintain their mental freshness and alertness. For the same reason, it is important for the O.R. staff to keep regular office hours, and for overtime spent in special reading to be kept to sensible proportions.

1.3.9 Organizing the job—*The team.* A very successful method for O.R. is the use of the team. Once a job has been definitely accepted, it is analyzed and assessed as described previously. During this process, the size, form, and membership of the team will emerge. The team will include one or more O.R. workers, together with technical representatives from the departments whose work comes into the picture. An informal working party of about five members is probably the most successful arrangement.

The team method proved outstandingly successful in the material control simplification mentioned above. The team consisted of representatives from planning, material control, purchasing, and accounts, together with the O.R. worker. The general idea was, "We are going to produce a joint scheme that will make life more pleasant for all of us." Although the improved methods took a good deal of hammering out and many mutual concessions among the different departments represented, a simple, smoothly working scheme finally emerged. This scheme was submitted to the chief engineer, who accepted it and put it into use with satisfactory results.

The great virtue of the team method is that all the members of the team have a stake in the success of the project. Preliminary suspicions soon disappear; technical and other information is pooled, and each member uses his imagination in working toward the common goal. A secondary but important advantage is the flexibility of the method. In any organization, the small O.R. department cannot hope to have sufficient specialized technical knowledge to cover every section. Nor will it have the necessary "political knowledge"—that is, whom to tackle for information and action. But it can always find people who do know and who can be co-opted as needed.

If the team does not include the top executives from the different departments, it is essential that these executives be kept fully aware of progress either through informal interim reports or by personal discussion.

Experiment or plant data. One of the most important techniques developed during the past few years has been the statistically planned experiment. Originally used in biological and agricultural work, this technique has become a powerful industrial tool. The planned experiment tackles a multiple-factor situation as a whole, even when there is a large number of factors. This approach has several advantages over the older method, in which factors are examined one at a time. In the first place, to eliminate all factors but one may be possible only under laboratory conditions, with a consequent loss of reality. Furthermore, the older method is slow. By dealing with all the factors at once, however, it is possible to assess the strength not only of each main effect, but of what are called "interactions." In examining

heat distribution in a billet reheating furnace, for example, it was found that not only did the temperature vary from one end to the other, as had been expected (main effects), but from one side to the other at the "entry" end, and in a different way from one side to the other at the "exit" end (interactions).

The O.R. worker uses the planned experiment wherever possible. Frequently, however, practical reasons, such as interference with production schedule, make it impossible to use the planned experiment in industry. In such circumstances, the O.R. worker must use routine office or plant information, but the reliability and form of such information are so important that he must exercise special care. It is worth while for the O.R. worker, if he is not already so acquainted, to become familiar with the design of simple record forms, and with present-day methods of mechanization, including the various manual and machine punched-card methods, and the design of nomographs and special slide-rules.

The general point of view on routine production data can be illustrated by an actual example. An inquiry was to be made to discover the main causes of defects arising in the manufacture of steel rails, so that remedial measures could be taken. The O.R. worker convinced himself by direct inquiry that the recording of information was being carried out honestly and carefully, but that (1) There were certain types of information apparently found useful in other steelworks that were not being recorded in this instance. (2) Identity appeared to be kept through the ingot stage by the careful watching of trained observers, but the hot stamping of identification numbers on finished rails was not 100 per cent reliable. (The number of the ingot in the cast and whether the rail came from the top, middle, or bottom of the ingot were important pieces of information, and keeping track of identity throughout a series of processes was important.) And (3) the information was being kept on a variety of forms, with no single cast history sheet.

These points were put to the management. As a result, (1) it was arranged that records be kept of the missing pieces of information until they were proved useful or useless; (2) hot stamping was reorganized; (3) the O.R. worker was asked to design a case history sheet, which he did, working jointly with the steel control department.

Fortunately, dishonesty in recording is not common, and there are simple statistical devices for checking when it does occur. Laziness, especially on night shifts, is not unknown, and must be guarded against. A row of absolutely constant readings is always suspect.

1.3.10 Method. The methods available for O.R. work are so diverse that it is impossible here to do more than refer the reader to the bibliography that appears at the end of this section. There is also a list of societies in Great Britain, Canada, and the United States that are interested in O.R. or in one of its related activities.

1.3.11 Recommendations and results. It has been said that the function of an O.R. department is to make its inquiry and to report the results. Ideally, however, the O.R. department must not stop once it has reported the results; it must make recommendations that will lead to action. The form of the recommendations varies according to the type of result. On one occasion, for instance, the net result of a laborious inquiry was a recommendation to the management not to buy a new overhead crane. In another case, the recommendation was that if special attention were paid to three of the eighty factors that had been found to be important, the percentage of the particular defect complained of would be halved. When management acted accordingly, the promised result was obtained.

1.3.12 Reports. Throughout a long investigation, verbal contact must be maintained with higher authority. But the eventual findings must be presented in a report; the form of report is more important than is sometimes realized.

Good practice is to direct each report primarily to the particular person who

is most interested—Mr. X, the director, works manager, chief chemist, and so on—bearing in mind his personality and background, and secondarily to the technical heads of departments who will implement its findings. Since Mr. X wants the results and the proposed actions, there should be a summary at the beginning of the report: Object; Results; Recommendations. Although this summary may be sufficient for Mr. X, it is also necessary to give full technical details to the mill managers, engineers, chemists, and so forth, who will apply the recommendations. Tables of data and discussions of the techniques (all of which incidentally are valuable reference material for further work) should be given as Appendices.

1.3.13 Follow-up. Like the members of any other department in an industrial organization, O.R. workers have to prove their worth. It is quite essential that they follow up on their recommendations to see what happens and to assess the results. It is interesting to analyze some of the following case histories from this point of view. The steelworks control plan, for example, is still under trial, but has produced promising initial results. The textile machine study actually produced the calculated economies. The plant traffic investigation led to the economies expected and prevented a heavy capital expenditure that had been proposed. The investigation of losses in the manufacture of a ceramic product led to simple changes in procedure that cut the losses to almost zero.

1.4 NOTE ON THE CASE HISTORIES

The case histories that follow come from different industries in

O.R. CASE HISTORIES

Contributor	*Title*	*Main Techniques Used*
Sebastian Littauer Executive Officer, Department of Industrial Engineering Columbia University, New York	The Economic Control of a Book-Manufacturing Plant	Quality Control Charts, Information from Works Data.
Charles A. Bicking Office of the Chief of Ordnance Washington, D. C.	O.R. in a Chemical Pilot Plant	Relationship Analysis, Information from Works Data.
John Murdoch English Electric Co. Ltd. Rugby, England	Materials Handling in a Heavy Machine Shop	Data from Special Time-Study, Analysis Based on Theory of Congestion.
F. A. A. Menzler, C.B.E. London Transport Executive	O.R. at London Transport	Planned Experiment and Associated Techniques.
O. W. Hamilton The United States Time Corporation Waterbury, Connecticut	Improving the Technical and Cost Position of a Ceramics Manufacturer	Planned Experiment and Associated Techniques.
Professor C. West Churchman Case Institute of Technology Cleveland, Ohio	The Application of Sampling to L.C.L. Interline Settlements of Accounts on American Railroads	Statistical Sampling.
W. S. Sondheim Ashton Bros. Ltd., Hyde Cheshire, England	Obtaining Maximum Efficiency from a Barber-Colman Automatic Knotter	Maximization of Operating Equation.
Stafford Beer S. Fox & Co. Ltd., Stocksbridge Nr. Sheffield, England	*An Original System of* Control in a Steelworks	*Indices of Productivity,* Nomograph, Planning Board.

America and Great Britain. The accounts conform in general but not rigidly to the basic plan given below. The variations are so interesting, reflecting the differing personalities and circumstances, that editing has been kept to a minimum. The contributors and the writer are indebted for useful suggestions to Miss D. B. J. Edgley, Courtaulds Limited.

Basic Plan for Case Histories of O.R. Job.

1. Type of person in charge.
2. Origin of job.
3. Analyses.
4. Results.
5. Recommendations.
6. Follow up.

2. APPLICATION OF OPERATIONS RESEARCH TO THE ECONOMIC CONTROL OF A BOOK-MANUFACTURING PLANT, SEBASTIAN B. LITTAUER

2.1 PERSON IN CHARGE OF O.R. WORK

Trained as a mathematician and engineer, with the degrees of A.M. in Mathematics, Columbia University, Ch.E. from Rensselaer Polytechnic Institute, and Sc.D. in Mathematics from Massachusetts Institute of Technology. Has special interest in electronic control instruments and the application of statistical quality control and the experimental approach to the economic control of industrial operations. As a Professor in the Department of Industrial Engineering, Columbia University, is concerned with the teaching of Statistical Quality Control and Operations Research. Is also a consultant to industry in the same activities.

2.2 PRELIMINARY INFORMATION

This organization is engaged in complete book manufacture. It operates two shifts regularly and a third shift to a lesser degree, with a total employment of approximately 700. There is no research department in the corporation, although in many of its operations there is experimentation with new methods.

The president of the corporation is the principal stockholder and chairman of the board of directors. He is, in effect, the active head and top policymaker of the corporation. In the present case, the president felt that because of economic conditions and because of relations with certain publishers, an examination of the economic control of the corporation's manufacturing operations was in order. In particular, his interest had been aroused by some popular articles on statistical quality control. He wanted to know whether the control of quality was one of the significant keys to cost reduction.

The writer was called in to discuss the matter. After two conferences with the president and three other representatives of top management, it was agreed that an investigation should be made for the purpose of evaluating the effectiveness of present manufacturing controls and of recommending measures for optimizing economic control of the manufacturing operations.

2.3 ANALYSIS OF THE PROBLEM

Essentially, the problem resolved itself into the following items:

1. To specify the distinct classifications of activity of which book-making is composed in such a way that each lends itself to a set of operationally corrective controls.

2. To determine a ranking among these classifications in the sense of their economic importance to the continuing net corporation profit.

3. To establish systems of controls, beginning with the most important category.

2.4 GROUNDWORK

After discussion, it was agreed that the consultant should work with a team drawn from within the

organization. This team consisted of the plant superintendent's assistant (full time) and the plant superintendent, the printing room superintendent, and the bindery superintendent (co-operating associates). Since the consultant was not available full time, a working schedule was arranged for the equivalent of two days per week. The active investigation took seven weeks, and the final report was completed during the three weeks following.

First, discussion was concerned with classification of activity. The major classifications were (1) manufacturing, (2) sales, (3) executive, (4) accounting, (5) administrative, and (6) distribution. On further consideration, "manufacturing" was subdivided into three organization groups: (a) composing, (b) printing, and (c) binding.

Interviews were held with all departmental chiefs in order to rank the categories in importance. At the same time, members of the working group made complete technical flow charts of the whole business processing of a sale, and of the whole manufacturing process. Both the interviews and the flow charts were completed in two weeks.

"Quality" was a term that occurred in all discussions and from the following points of view:

Effect on goodwill of publishers.

Effect on losses in printing.

Effect on time of make-ready and hence printing cost.

Effect on amount of inspection.

Control of quality, in fact, seemed to be the focus of the investigation.

2.4.1 Composition. One of the key phases of book making is composition. The problems of composition were considered, but, unfortunately and, in the opinion of the writer, mistakenly, they were not given the attention they deserved. It was felt that since the techniques of composition were going through many technical changes they would not be suitable for operational analysis. The writer acceded to the views of the group, but he believes that useful contributions to the economy of book making could have been made by a study of the composing techniques that were then in a state of development.

2.4.2 Printing. In printing, the first problem was to determine an operational meaning of quality and to establish quality standards. Examination of work procedures and rates of performance of various productive operations was undertaken in detail. It was decided to study the history of two presses long enough to determine the state of control of those printing operations and the various significant factors which contributed to the quality and costs of the final printed page. A log of information, beginning with "make-ready" and ending with the printed sheet, was maintained on two different presses for 11 working days on two shifts.

One of the principal problems to be resolved hinged around the following factors: the effects on producing quality of (1) management, (2) worker, (3) raw materials, and (4) equipment.

2.4.3 Binding. The bindery operation was classified into ten basic stages, which were examined and reviewed. Here the degree of mechanization was such that further useful study, within the scope of the investigation, could come only from analysis of the final inspection of the finished bound book. Using available information on past 100 per cent inspections, sampling studies were run:

1. To estimate the quality level of binding and printing so far as inspection at this stage could evaluate printing.
2. To determine the state of control of the completed binding operation.
3. To compare the relative effectiveness of first and second shifts.
4. To determine whether sampling inspection could safely replace 100 per cent final inspection currently in use.
5. To determine how much money could be saved if sampling inspection proved effective.

2.4.4 Packaging and distribution. Technical modifications of methods which might yield greater efficiency in the packaging and distribution phases of the plant were considered. Raw ma-

terials and their storage were also probed, with the conclusion that raw materials could best be handled by the vendors, who were giving the plant excellent service. Further inquiry would be outside the limits of the investigation. Storage and the flow of materials from the source were studied and general recommendations were made.

2.5 COLLECTION OF DATA

A great deal of work was necessary to prepare both the conditions of operation and the factory staff for the collection of data. Foremen had to be convinced that this work was both necessary and to their advantage. It was quite a task to convince the workers that the whole investigation was not just some means to effect a "speed up" and to undercut their jobs. It was also quite a task to arrange conditions so that sampling could be undertaken in the bindery without upsetting the production schedule, and it was a harrowing task to dig up past information. However, satisfactory preparations were made and, with a few exceptions, information was collected in a smooth and systematic manner, under close supervision.

2.6 ANALYSIS

Complete analysis will not be given here, but an indication of the types of analysis is given below.

2.6.1 Printing. The data on the make-ready time and operation of the presses indicated a much higher proportion of down time for the presses and a greater time of actual repair than had been on the record. What these data suggested, however, was of far greater importance, namely, that the time spent on make-ready seemed to depend on the judgment of the pressmen. Apparently, two different pressmen might differ as much as 25 per cent in the time used to make-ready. Furthermore, this difference in opinion was carried to such an extreme that if a make-ready were begun but not completed by one pressman, the pressman on the next shift would tear down his predecessor's work and begin the make-ready anew. What was needed here was a standard of quality of print and color, together with a definite systematic procedure of make-ready. With this procedure in operation, it should be possible to save on make-ready time.

Other factors contributing to the nonuniformities in make-ready and wasted time in successive correction of make-ready were caused by the condition of the presses and of composition. With more uniform cylinders, more consistent ink flow, and a composition free of irregularities, at least 25 per cent of the time devoted to make-ready could have been saved.

Analysis of the printed sheets as well as observation of the manner of their inspection showed no systematic conception of standard quality of the printed page. It definitely appeared that an operationally verifiable concept of standard quality of the printed page was essential if economic control of the printed sheets was to be obtained.

2.6.2 Bindery. In the bindery, the 100 per cent inspection data and the sample inspection data of the finished book were analyzed by conventional fraction defective control chart methods. This analysis led to the following simple results: 1 per cent of books at this inspection during the day shift were found to be defective, whereas the average per cent defective found during the night shift was one-half of 1 per cent. The fraction defective level was in the conventional state of control on each shift. There seemed to be no reason why there should be a difference in quality in the books inspected during the two shifts, and this difference was ultimately attributed to laxity of inspection on the second shift.

The sample inspection control charts demonstrated the same pattern that the corresponding 100 per cent inspection control charts demonstrated. But the sample inspection estimate was consistently higher than the 100 per cent in-

spection estimate. Apparently, sample inspection was much more exacting than the 100 per cent inspection. These findings were sufficient to lead to constructive recommendations.

2.6.3 Special problems. Among the special problems analyzed was that of "shortages." When a book is made that comprises more than one signature, it is possible that more or less than the quantity ordered of any one signature may be ready-for-the-binding stage. In an order of 1,000 books, the number of completed signatures may vary, say from 950 to 1,250. Since only 950 complete books can be made, the surplus represents a loss in both paper and the cost of printing, as well as a loss of the income from 50 books. Some accountants believe that this loss is partially compensated for by the overages—that is, the number of completed books beyond what the order called for, all of which can be billed.

The team sought to investigate the causes of shortages and overages, their relationship to the state of quality, the magnitude of the losses involved, and the potential savings. To analyze the case of shortages, two parameters were considered:

1. The range fraction, which equals the difference between the highest and lowest count among the signatures for one book, divided by the size of the order.

2. The fraction short, which is the number of books short, divided by the size of the order.

Control charts for fraction defective were made for both the range fraction and the fraction short for the last 31 shortages.

Analysis of the data and charts showed that:

1. The average fraction short agreed with the percentage loss in dollars owing to shortages which the controller had estimated.

2. Both the range fraction and the average fraction short were badly out of control.

3. The lack of control provided the clue to the causes of shortages.

Inaccurate paper count and spoilage in printing caused by the uncontrolled quality of printing were the chief causes of shortages (losses in binding and handling were not large). An analysis of overages indicated the same basic causes. Hence elimination of shortages or overages required uniformity of the quality of printing, which included uniformity in paper count.

Although it will not be explained in detail, it can be readily shown that increasing the uniformity of the quality of the printed page effects a considerable saving in paper allowance in addition to reducing shortages.

2.7 CONCLUSIONS

1. The principal conclusion of the investigation is that a comprehensive statistical quality control system is called for. As a corollary, the effective operation of the quality control system would result not only in improved quality and reduced costs but in increased profits through improved public relations. The most needed requirement in the printing industry is the development of objectively verifiable standards of printing quality.

2. *Make-ready.* The present procedure of make-ready is neither standardized nor uniform, and is undoubtedly uneconomical. Average times for make-ready could be reduced by about 25 per cent, and personnel should be trained by the quality authority to perform make-ready in a consistent fashion. Equipment needs to be improved and maintenance has been and is quite inadequate.

3. *Printing.* The loss of printed sheets is higher than it need be, and much of the non-uniformity in printing quality is due to non-uniformity in make-ready. The poor state of equipment accounts for much of the defective printing quality.

4. *Binding.* Bindery operations are highly economical and in a good state of control. There is evidence that economic gains could be made by the introduction

of acceptance sampling and control chart procedures in the final inspection stages.

5. *Special problems*. There are many special problems which need consideration, one of which is the problem of shortages. Losses from shortages are due to lack of control in the printing operation and amount to some $50,000 a year. Much of this loss could be saved by an efficiently working statistical quality control system. Losses from overages, resulting from the same causes as shortages, can be considerably reduced.

6. At least $100,000 could be saved by effective economic control of the manufacturing process of book making at this plant, and it is believed that at least one-half of this amount could be saved by means of an effective system of statistical quality control.

7. As a result of the consultant's experience and study of the economic control of industrial operations in general, not as a result of this investigation, it is asserted here that mass production is the responsibility of management. However cooperative or uncooperative labor may be in carrying out mass production, the economic success is completely the responsibility of management. More than that, it is management's life or death. Hence, these conclusions and such recommendations as are made below must be viewed in the light of efficient survival.

2.8 RECOMMENDATIONS

A brief résumé of the recommendations will be given here.

There shall be designed, organized, and instituted a comprehensive statistical quality control system. The system is not detailed here, but some suggestions are given as follows:

1. The quality control department is to operate as an independent, responsible unit, and the department's director (who is to be the plant superintendent) is to report to the president of the corporation.

2. There shall be quality managers of printing, binding, and composing, who are to be the present superintendents respectively of printing, binding, and composing. This recommendation is in keeping with the principle that the productive unit shall be responsible for its own quality.

3. There shall be two new appointments to the quality control department. The first is the appointment of a quality authority. This activity is well understood in the printing industry but is not uniformly practiced. Details of the quality authority's functions and duties were made, but are not detailed here. The second appointment shall be that of a quality analyst, who should have a considerable background in the science of statistical quality control.

4. There shall be established a quality control committee, whose membership shall consist of the following:

Director of quality control.

Three department quality control managers.

A representative from the controller's office.

A representative from the purchasing agent's office.

A representative from the sales manager's office.

The quality analyst shall be secretary to the committee, which shall not have executive authority but shall function for the purpose of facilitating good relations and understanding within the plant as well as with both vendors and clients.

5. The quality authority shall be solely responsible for the establishment of standards of quality and for the training of pressmen, make-ready men and others with respect to developing uniform judgment of quality standards. He shall be directly responsible to the director of quality and the efficient functioning of this department will depend upon good relations between these two persons.

6. A permanent operations engineering team shall be established for regular investigation and review of both the technical and the economic phases of functioning of the plant, as well as for consideration of special problems. De-

tails of the organization, personnel, and functioning of the proposed team shall be worked out in conference between the present operations team and the corporation officers.

2.9 REPORT AND FOLLOW-UP

A comprehensive report of 60 pages, including some detailed discussion of the technical aspects of the problems considered, was presented a few weeks after the close of the investigation. The report, which contained both recommendations and conclusions, was issued without any further discussion with the top executives.

Some two months after the report was submitted, the president called the operations team together and stated that it had been decided to follow the recommendations of the report. Four of the officers and three of the plant staff had read through the whole report and were enthusiastic about carrying out its recommendations. Discussions were held on setting up a continuing operations engineering team, headed by the consultant, the team to be instituted following an impending merger. Since the merger negotiations took longer than was expected, this consultant was not available when management undertook to set up an operations engineering team. It is understood, however, that these recommendations have been followed in essence.

3. OPERATIONAL RESEARCH IN A CHEMICAL PILOT PLANT, CHARLES A. BICKING

3.1 PERSON IN CHARGE OF O.R. WORK

Trained at University of Delaware, with degree of B.S. in Mechanical Engineering; Massachusetts Institute of Technology with degree of M.S. in Business and Engineering Administration; graduate studies in Management, Quality Control, and Design of Experiments at University of Pennsylvania, Rutgers University, University of Delaware, Columbia University, and Massachusetts Institute of Technology. Is a Founder Member and Fellow of the A.S.Q.C., member of various committees of the A.S.T.M., member of A.A.A.S., A.S.A., I.M.S., Biometrics Society, etc. Has had long and varied teaching experience in Quality Control and Industrial Experimentation. Main professional experience as Quality Control Engineer with the Hercules Powder Company, Wilmington, Delaware. At present, Chief, Design of Experiment Unit, Research and Development Division, Office of the Chief of Ordnance, Washington, D. C.

3.2 THE PROBLEM

This job was accomplished in one of the several plants of a large concern that manufactures a variety of chemical products. The problem was tackled on unconventional lines. A pilot plant was involved in the development of working principles and techniques for economic manufacture of a pyroligneous alcohol. It will be described in simplified general terms for the benefit of readers without technical training in chemistry.

A modified product of the solvent extraction of a soft wood was subjected to high temperature and pressure in the presence of a catalyst. The reaction was endothermic and its rate could be controlled to some extent by the rate of application of heat. The process was semicontinuous, in that it was necessary to interrupt the steady, slow pumping of the raw materials through the reactors at certain periods in order to restore exhausted catalyst. The complete reaction was accomplished in two stages and, at the start, was handled in conformance with normal practice. This meant that the fresh raw material was pumped first through the reactor containing partially spent catalyst and then through the second reactor containing fresh catalyst. The efficiency of alcohol conversion was known to be complicated by factors of temperature and catalyst condition.

Theoretical optimum alcohol content of the product was about 90 per cent. Inexact controls and secondary reactions produced by-products to account for the remaining 10 per cent. The extent of the conversion of the original material could be determined by measuring some property of the product in semi-finished state in the first reactor or in its finished state in the final reactor. At the time of the investigation, control was being exercised by comparing the theoretical alcohol content of a final reactor sample for which a saponification number was measured with an actual determination of the alcohol in the sample. If the alcohol analysis of the sample was less than the theoretically computed alcohol, the reactor temperatures were lowered on the assumption that excessive temperature for the existing catalyst strength was causing side reactions which formed excessive hydrocarbons. The time involved in calculation and the necessity for making assumptions made this an unsatisfactory basis for control.

3.3 THE TEAM

The team, comprising very diverse individuals, came together more or less by chance, met only once for a brief time, and thereafter carried out plans and achieved results very rapidly. Data already at hand were used almost exclusively.

The team included a staff engineer assigned by the central office to a plant that manufactured a line of organic chemicals. As in many chemical plants, most of the process development was done by the local laboratory under the supervision of the chief chemist. One of the project development engineers from the local plant laboratory was the second member of the team.

At this time, the home office of the company was providing a new and specialized advisory service to the plants in the form of assistance in the introduction of statistical methods of process quality control. The quality control staff had recognized, however, that in the chemical industry the study of analytical precision and the statistical design of experimental work should accompany or precede attempts toward process control. The company quality control engineer was therefore spending some time at the laboratory in order to induce chemists and development engineers to expand their use of statistical methods. The quality control engineer was the third party to the plan to be described.

All three men had known each other for some time. The two from the home office, although they did not ordinarily work as a team, both had several years' background similar to the operations research concept of solving production problems, and both had expressed willingness to work together with interested plant engineers on current development problems. It was the development engineer who suggested that the pilot plant operation to which he was assigned should be investigated.

3.4 ANALYSIS

The group of three interested people met at the laboratory one morning to discuss the possibility of a chart method for control of the pilot plant. Data from a special pilot plant run were available. Samples had been taken at 14 intervals over a period of about 26 hours, and duplicate or triplicate tests had been made on each sample. Measurements of the product refractive index and bromine number were available, in addition to the usual determinations of percentage alcohol and saponification number. The ranges of the tests in each replicate set were used as a basis for determining the precision of each of these test methods. The relative precision of the saponification number confirmed the use of that test as a control measurement. The precision of the alcohol determination was also considered to be satisfactory.

Accordingly, a plot was made (see Fig. 15.1) of the data from the special run using saponification number on the

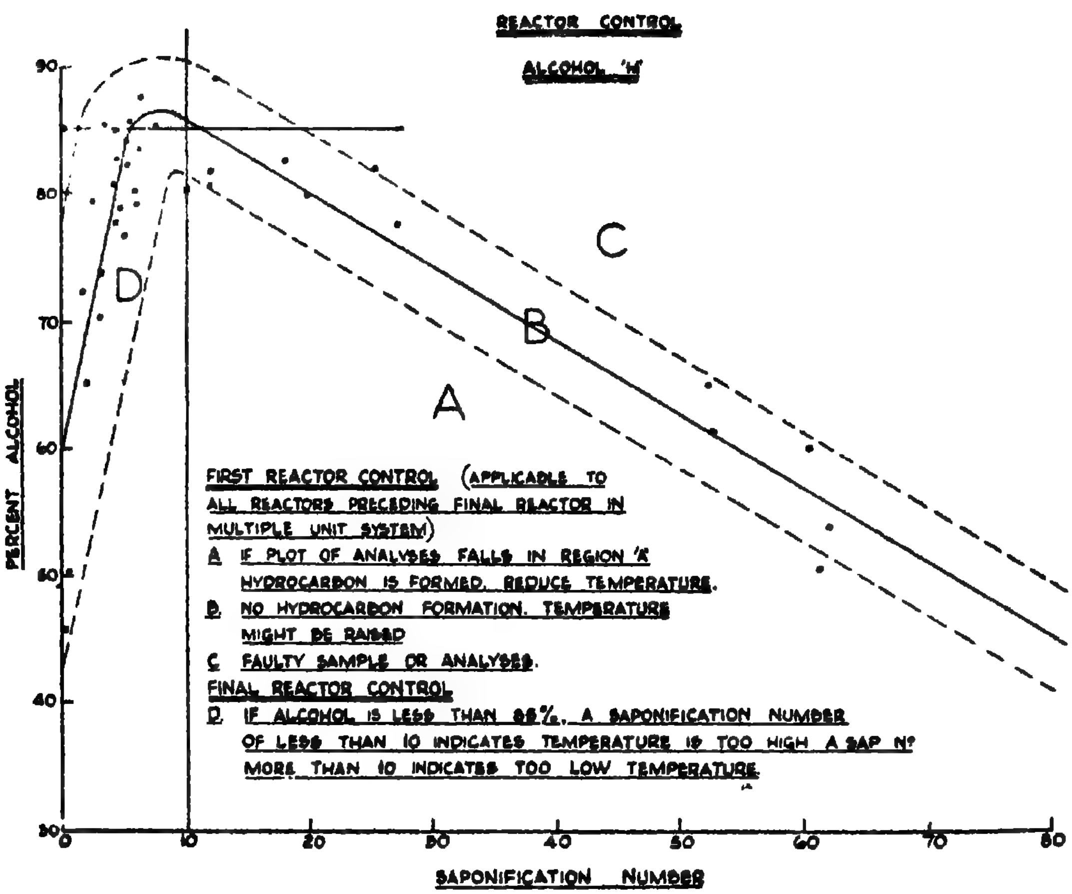


FIG. **15.1** CHART FOR CONTROL OF CHEMICAL PILOT PLANT.

horizontal scale and percentage alcohol on the vertical scale. The resulting scatter of the plotted tests confirmed what was known about the behavior of the reaction. The close practical confirmation of the theory clearly indicated that the critical point of the reaction was reached when the saponification number approached the neighborhood of 10. A solid curve was fitted to all the plotted points by eye. Plus and minus limit lines were drawn about the curve such that 95 per cent of the single determinations should lie within them if the proper temperature were maintained and if the catalyst were not being exhausted.

3.5 USE OF RESULTS

The chart was to be used in the following way. For first reactor control, a point within the "B" area indicated no hydrocarbon formation and signaled the operator to raise the temperature of that reactor. Raising the temperature should cause the next sample to give a point further to the left along the curve and within the limit lines. This would be in the direction of higher conversion. A result in the "A" area indicated that hydrocarbon was being formed and that the first reactor temperature should be reduced. Experience showed that the extent of the temperature change required was proportional to the distance of the point from the limits. On the other hand, a point plotted in the "C" area raised doubt concerning validity of the sample or the test, since it was so far from the satisfactory performance curve. Resampling or a new test was called for.

For final reactor control, attention was paid to the extreme left area of the chart, area "D." If the alcohol content was less than 85 per cent and the saponification number less than 10, the tem-

perature of the reactor was too high. If with less than 85 per cent alcohol, the saponification number was more than 10, the temperature was too low. If temperature adjustments did not bring the samples back into the higher portions of the curve, the catalyst was changed in the more nearly exhausted reactor.

The operators were instructed to control the pilot plant on the basis of this kind of chart. They found that the method was much easier and quicker than the former tedious method of arithmetic comparison with theoretical conversion. With this chart as a guide, the project engineer began to experiment with different temperatures, pumping rates, frequencies of catalyst change, and numbers and arrangements of reactors. It was soon discovered that best conditions were produced by using the reactor with fresh catalyst ahead of the reactor with partially spent catalyst, in contradiction of accepted procedures. The chart was thus a big factor in obtaining optimum operating conditions.

3.6 FOLLOW-UP

Upon enlarging this operation to a full-plant scale, similar charts were used as a means of process control. The operators were thus provided with a visual tool for the best control of the process, which minimized the time required to determine what adjustment to make or to decide when not to make adjustments at all. Savings arose from a significant reduction in the time and experimentation required to determine the best conditions of operation while still in the pilot plant stage. Experimental efficiency was improved by an estimated 10 per cent, and even larger savings resulted from the reduction in operator time required in routine production

These results were reported in the formal laboratory report on the development and received warranted attention as an efficient approach that could be recommended for other projects throughout the company. Subsequently, numerous small engineer-statistician teams were used. Results were often good, but seldom was a job done with such straight-forwardness and lack of formal pre-planning as in the case described above. One might speculate on what elements in this situation caused it to be remembered as so remarkable. It may be simply that all the essential conditions for successful operational research were fully satisfied.

4. APPLICATION OF OPERATIONS RESEARCH TO MATERIALS HANDLING IN A HEAVY MACHINE SHOP, J. MURDOCH

4.1 PERSON IN CHARGE OF O.R WORK

Graduated as B.Sc. in Electrical Engineering from Glasgow University. Following graduation, was an assistant for two years in the Statistical Section, The United Steel Companies, Ltd. For three years has been in charge of the Operational Research Department, English Electric Co. Ltd., Rugby.

4.2 INTRODUCTION

The approach to problems in handling is similar whatever the problem. Essentially it is to determine a method of summarizing the system into a series of statistics or handling coefficients which will form a mathematical model of the system. This model must satisfy the following conditions:

1. It must represent the system with a known degree of error.
2. It should be capable of estimating and evaluating the effect of any possible change in handling practice.

4.3 STATEMENT OF PROBLEMS

Figure 15.2 shows diagrammatically the layout of the transport system under consideration. The system consists of a single-line rail track running from the fabrication department

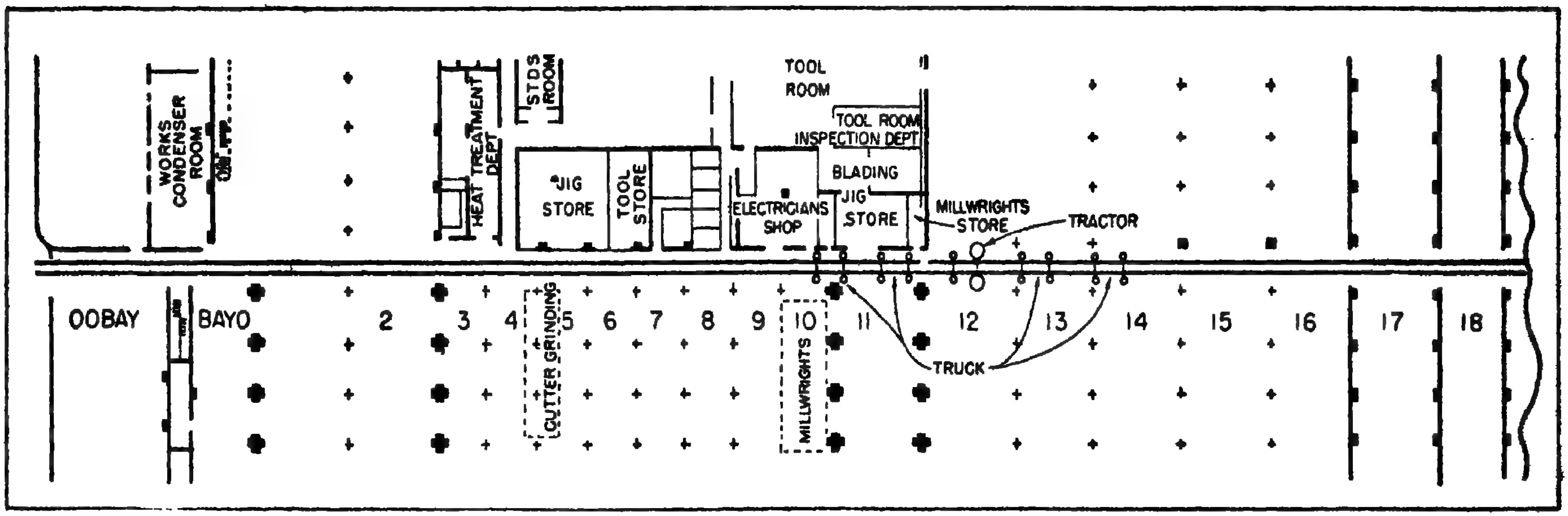


FIG. **15.2** LAYOUT OF SHOP IN MATERIALS HANDLING STUDY.

at one end to the erecting and forwarding departments at the other. Four low, flat rail trucks are employed and moved by means of one tractor. All components too heavy to be hauled by Lister trucks are transported on this system. The flow lines are two-way; loading and unloading are carried out by overhead bay cranes.

The problem put by the management was: "This rail system is not operating efficiently. Long delays are being experienced by our machines and operators in waiting for transport. What steps are necessary in order to achieve an adequate and efficient transport system?"

The problem can be restated as follows: "What is the handling potential of system with present shop layout or flow line pattern? How does this compare with volume of work to be moved?"

The handling potential must be defined for each problem. The definition is: "Number of jobs which system can move in a week."

Similarly, work potential is: "Number of jobs wanting movement in a week."

Since, however, these systems of transport are not stable—that is, the jobs to be moved arrive in a random manner rather than at regular intervals (Poisson-distributed) a further handling coefficient is required to complete the model of the system, namely: "The average and distribution of time interval between asking for move and transport calling for job."

Summarizing, the following three handling coefficients are required for the solution of the problem:

1. Handling potential (P).
2. Work potenial (W).
3. Average delay before moving ($\bar{\bar{D}}$).

4.4 PLANNING AND OBTAINING DATA

Once the problem has been broken down into its operational form, the next step is to decide on both the form and amount of data required for solution.

It has become standard practice with our department to obtain data by surveying the system in action and to build up a model from the data given by this survey, rather than to build up a theoretical model based on certain assumptions.

Figures 15.3 and 15.4 show the data sheets employed by observers on this survey. These forms were designed to give the following breakdown for every job moved:

1. Time job asked to be moved.
2. Time truck in position to move job.
3. Time crane started to sling job.
4. Time job on truck.
5. Time job arrived at destination.
6. Time crane started to sling job.
7. Time job off truck.
8. Details of journey; i.e., from Bay 12 to Bay 2.
9. All delays which occurred, together with reason. Typical causes of delay are:

a. Operators' personal delays, late starts, meal breaks, etc.

b. Waiting for tractor.

c. Blockage delays.

d. Breakdown, etc.

It is seldom possible, because prior information on these problems is limited, to fix accurately how long surveys will have to run before adequate data are assembled. Surveys are planned for one week's duration and are extended in cases where summary analysis of daily information shows a need for additional data. Normally, one week's data are adequate, providing external factors—i.e., level of production—are not abnormal. In this problem, one week's data were found adequate.

4.5 ANALYSIS OF DATA AND ESTIMATION OF HANDLING POTENTIAL OF SYSTEM

Table 15.1 gives a summary of the breakdown of total time taken to move job—i.e., between arrival of truck and job being lifted off truck at its destination.

The table shows that on the average

STUDY OF 06 SHOP
HEAVY TRANSPORT

DATE. 25-8-50......
SHEET... 1.............

OBSERVER.. F.SMITH..........

	Description of Job	Time Reported	Journey		Truck No.	No of Lifts	Arrive MG	Details of Journey				Unloaded	Remarks & Observations
			Frm	To				Start to Load	Finish Loading	Arr: Bay	Start Unload		
F1	½ NOSING	NIGHTSHIFT	12	15	2	1	NIGHT SHIFT	—	—	7:30	7.45	7:50	
			TRUCK NO. 3 ARRIVED IN 06 at 7:52										
F2	NOSING	7:30	14	00	3	1	7.52	7:50	7:55	8:12	8.15	8:19	
F3	1 H.P. SHAFT (BIRK)	7:40	13	00	2	1	7:58	7:59	8:06	8 11	10.20	10:27	[illegible]
F4	1 L.P. EXHAUST	7:40	16 WT	12	1	1	7:56	7:56	8:04	8 09	8:21	8:27	Crane working to 8:21
F5	8 DISCS (ROTOR)	8:35	12X	14	1	8	8:27	8:40	9.00	9 01 4 24	9:24 4:24	(1) (2) 4:50	[illegible]
F6	2 COOLER TOPS ½ HP NOSING (TOP)	8:50	16 WT	15	2	3	10:32	10:34	10:45	10 45	10:59	11:02	
F7	2 COOLER TOPS ½ HP NOSING (BFH)	8:50	16 WT	FAB	2	3	11:02	11:04	11:14	11 15	1:30	1:54	
F8	IP SHAFT (BIRK)	7:40	13	00	3	1	10:32	10:37	10:59	—	—	11:03	[illegible]
F9	DRAFT TUBE EXT	8:00	2X	00	3	3	11:07	11:09	11:49	1 40	2:00	2:38	[illegible]
						LUNCH BREAK							

FIG. 15.3 DATA SHEET FOR MATERIALS HANDLING STUDY.

STUDY OF 06 SHOP HEAVY TRANSPORT

DATE. 25-8-50...   OBSERVER...............

DELAYS AND BLOCKAGES (B)

Job	Duration of Delay From	To	Position	Reason & Remarks Truck No......
1	9:00	9:13		Tea Break
2	8:00	1:30	Forwarding	Crane broken down. H.P. staff in M.C. (forwarding) holding up empty
3				truck No 3 in OO for returning
4				to 06
5				Jobs for forwarding going to
6				OO Bay where they are loading
7				onto road transport
8	11:50	12:00		Stop work
9				
10	12:00	1:00		Lunch Break
11				
12	1:00	1:08		Late start crane men
13 b) Crankcase	2:12	2:26		Turn over in M.C.
14				
15				
16				
17				
18				
19				
29				
30				

FIG. 15.4 DATA SHEET FOR MATERIALS HANDLING STUDY.

it takes 51 minutes from the arrival of the truck at the dispatch point to the time when the job is unloaded off the truck at destination. The table also shows that long delays are being experienced in all three elements. (Note: Personnel delays have been excluded from all figures given in analysis.)

Let us now consider each element in more detail:

1. *Time interval between truck arriving at bay and being loaded* (A). This time interval was further subdivided into:

a. Average true loading time per job —7 minutes.

TABLE 15.1. BREAKDOWN OF TOTAL MOVEMENT TIME*

	A	B	C	
	Time interval between truck arriving at bay and being loaded	Time interval to reach destination	Time interval between arriving and being unloaded	Total
Average	14	20	17	51
Range	2-110	0-226	4-99	—

* All figures in minutes.

b. Average delay waiting for crane per job—7 minutes.

2. *Time interval between truck arriving at destination and being unloaded* (C). This time interval was further subdivided into:

a. Average unloading time per job—18 minutes.

b. Average delay waiting for crane per job—9 minutes.

On these loading and unloading cycles one must consider whether the average delay of seven to nine minutes that is being experienced per job is as low as possible. As a guide to solution, these delays were subdivided by bay. Table 15.2 gives the picture for one section.

The table shows that generally in the three cases with asterisks the delay in unloading was significantly higher than the delay in loading. This point illustrates the personnel side of the problem, namely that bays are generally more cooperative in dispatching than in receiving jobs, unless they have machines or operators waiting for jobs.

By using the theory of congestion,* we can estimate the expected delay. Two factors are necessary:

1. Utilization of bay cranes (W).
2. Average holding or job times ($\bar{T}$) together with distribution.

In two cases,[4] namely with constant holding time or exponential holding time, the theory has been fully developed.

This case fitted an exponential distribution of holding time and, theoretically, it was deduced that the system was capable of operating at a level of three minutes average delay per job on loading or unloading.

Thus over half the delay experienced has been due to looseness in the system, a fact which was confirmed in later surveys by observing the time trucks were waiting when the crane was idle.

Thus the tightening up on cooperation between transport and bay cranes

* T. C. Fry, *Probability and Its Engineering Uses* (New York: D. Van Nostrand Company, Inc., 1929), Chapter X.

TABLE 15.2. DELAY WAITING FOR CRANES IN HEAVY MACHINE SHOP BAY

Wait	11	12	13	14	15	16
Waiting to load	4	8	5	5	14	2
Waiting to unload	2	5	12*	6	22*	12*

* Significant difference.

will reduce the delay in waiting to load or unload from seven to nine minutes to three minutes on the average.

3. *Journey time or time to reach destination* (B). The journey time per job was divided into:

1. True journey time (truck moving)	Negligible
2. Average delay due to blockage	2.9 mins.
3. Average delay waiting for tractor	3.6 mins.
4. Average inherent interference	13.5 mins.

This subdivision is standard for all systems. Inherent interference measured the delay caused by the interference of trucks with one another, the interference of trucks with tractor, and so forth, and is present in all systems where the number of flow lines exceeds the number of paths. Inherent interference is extremely difficult to isolate. The practice normally employed is to obtain it by the residual method—i.e., the total journey time is measured and all journey delays are subtracted. The residual is the inherent interference of system. Thus in this case:

$$\text{Inherent Interference} = 20 - 2.9 - 3.6 = 13.5 \text{ mins.}$$

Referring to this detailed analysis:

Blockage delay—This delay arises mainly from the necessity for turning over large components in the gangway because of space limitation in bays. From further analysis it was decided that these delays could not be reduced because of this limitation of space.

Waiting for tractor—This delay arises from the practice of employing only one tractor covering four trucks operating independently.

Inherent interference—The high level of this delay results from the lack of degrees of freedom in the system. It can be reduced by introducing more degrees of freedom into the system—i.e., by an alternate path, by-pass points, use of another tractor, and so on. From an analysis of possible methods of reducing this inherent interference, it was decided to introduce another tractor into the system. This step will also reduce the delay waiting for tractor to zero.

Utilization of trucks—The true utilization of trucks is given by:
Truck Utilization (U_T) = True loading

$$\text{Truck Utilization } (U_T) = \frac{\text{True ldg.} + \text{Unldg.} + \text{Journey Times}}{\text{Available Time}}$$

$= 30$ per cent.

4.6 CONCLUSIONS

1. Tightening up on cooperation between transport and bay crane will reduce delay waiting to load or unload from level of seven to nine minutes to three minutes on the average.

2. Inherent interference can best be reduced by introducing another tractor into the system. This step will also eliminate delay waiting for tractor.

3. Blockage delays in main cannot be reduced at present because of limitation of space in bays.

Implementation of these steps will give the following reduction in total journey time.

	Present	*Expected*
Delay loading	7	3
Loading time	7	7
True journey time	Ngble.	Ngble.
Blockage delay	2.9	2.9
Tractor delay	3.6	0
Inherent interference	13.5	7 (Est.)
Delay unloading	8	3
Unloading time	9	9
Total	51 mins.	31.9 mins.

Thus the implementation of these conclusions will give approximately 40 per cent reduction in journey time.

4. The last analysis on which the decision will be made on whether or not the new system is adequate is an estimate of the delay between asking for job to be moved and transport arriving to unload job (D). For a system based on the recommendations, the

theory of congestion indicates that approximately 60 per cent of jobs will be moved within one hour of requesting and that only approximately 5 per cent should wait for longer than two hours.

4.7 RECOMMENDATIONS

On the basis of truck utilization, total journey time, and delay waiting for movement, it was decided that the transport system was adequate. The main recommendations were:

1. Introduction of another tractor.
2. Tightening up on crane delay.

4.8 IMPLEMENTATION OF RECOMMENDATIONS

The standard practice is for O.R. to submit a report of recommendations to the management for approval. Where possible, cost estimates are also given. In this case, the report was adopted and implemented as soon as possible.

4.9 CONFIRMATION OF ANALYSIS

The last step is for another survey to be made later to check that the estimated efficiency has been achieved. The following results were obtained after six months of operation.

Loading delay	8.4 (including unloading delay)
Loading time	6
Journey time	Negligible
Tractor delay	0
Blockage delay	2
Inherent interference	8
Unloading delay	(See loading delay)
Unloading time	6
Total	30.4 minutes

Delay between asking and moving:

Under 10 mins	38 per cent
Within 10-60 "	31 " "
60-120 "	22 " "
Over 120 "	9 " "

A comparison of these results with those estimated from the first survey shows that within limits of error the conclusions have been confirmed in all cases.

4.10 VALUE OF APPROACH

The main value of this type of approach to industrial problems is that it gives management an objective basis on which to make a decision.

If the analysis outlined had shown, say, that the potential of the system could not be increased to the desired level without major alterations (such as the provision of the additional gangway which was under consideration when the survey was started), it would have been just as valuable to the management, since the analysis would have shown exactly what would be achieved by the expenditure of capital and why it was necessary.

However, from the actual results, the main value of the analysis was that it showed that what looked on paper and in operation to be a hopeless system, could be made adequate by means of certain minor changes.

Thus one of the major problems was eliminated. The analysis prevented the large expenditure on the proposed new gangway, saved thousands of pounds, and also prevented the loss of production space. The small incidental saving of time on large machines waiting for transport was approximately 35 hours per week in labor alone, giving £300 per year or lost production to the value of £2,000 per year.

5. OPERATIONAL RESEARCH AT LONDON TRANSPORT, F. A. A. MENZLER

5.1 PERSON IN CHARGE OF O.R. WORK

Holds the degree of B.Sc. (London); is an actuary by profession and immediate past-president of the Institute of Actuaries; a member of the Council of the Royal Statistical Society and the Council of the Association

of Incorporated Statisticians. Has been with London Transport for over 20 years, and is at present Chief Development and Research Officer, responsible for the direction of all scientific research, including operational, economic, and statistical, and of long-term planning projects.

5.2 DEVELOPMENT OF O.R. AT LONDON TRANSPORT

The London Transport Executive (commonly referred to as "London Transport"), previously the London Passenger Transport Board, is one of a number of "executives," including the Railway Executive and the Docks and Inland Waterways Executive. Since the nationalization of inland transport in 1948, these executives have been responsible, under the general direction of the British Transport Commission, for the administration of particular sections of the national system for transport. London's transport system—local surface and tube railways, buses, trolleybuses, and motor-coaches—had, however, been in a form of public ownership since 1933, when the then-existing municipal and private undertakings were taken into a single ownership by the newly constituted and autonomous London Passenger Transport Board.

Before World War II, studies of the performance of equipment under service conditions were undertaken. Nowadays, such studies would be regarded as O.R., even though the full apparatus of modern statistical techniques, including the design of experiments, was not utilized. Early examples were particularly concerned with the fuel consumption of the large fleet of buses operated by the former London General Omnibus Company—some 4,000 vehicles by 1933, when the enterprise was taken over by the London Passenger Transport Board. The fleet of buses grew to over 6,500 by 1948 immediately prior to nationalization. It was obvious in the examination of fuel consumption that the figures were affected by a multiplicity of factors, but in earlier days the methods of modern statistics by which the effects of individual factors are isolated were not available. Nevertheless, as long as 30 years ago it was known that there was a relationship between fuel consumption and atmospheric temperature. In the course of time, this relationship was expressed in a quantitative manner, so that fuel consumption figures could be corrected to allow for the effects of variations in atmospheric temperature.

Over the years, continuous efforts have been made to improve the fuel consumption of the bus fleet. Changes have been made in the settings of carburetors and fuel injection pumps, and in other directions thought likely to be beneficial. The effect of these changes has been determined by scientifically controlled tests under service conditions. Two groups of vehicles were employed, one of which served as a standard of comparison, and every effort was made to avoid altering more than one variable at a time. That the method of approach was fundamentally sound was demonstrated by the fact that very large reductions in fuel consumption were obtained by adopting the recommendations that arose from these tests. It is now known, however, that the precision of the tests was not as great as it was thought to be at the time, and that too little importance was attached to the inherent variabilities not only of fuel consumption figures but of the individual vehicles from which they were derived. It has also been learned that each bus performs a distinctive duty that affects its fuel consumption.

The introduction of new methods of O.R. has presented psychological difficulties in regard to acceptance, because of the long history of successful investigations on classical lines of experiment. The approach was made easier, however, by the coordination of the scientific aspects of the engineering services under an advisory Research and Development Committee which reports directly to the Chairman of the Executive, who takes a close interest in its work. This committee consists of the chief development and research officer (chairman), the

chief engineers, and the director of research. It sets up a team for each investigation project as it arrives. The team consists of representatives of the departments concerned, together with a scientific representative who acts as secretary and is largely responsible for planning the research and drafting the report. Usually, the team includes a statistician. The approach is that the "consumer" department is considered to be the client who is seeking assistance on a cooperative basis. If the report of the team is accepted after consideration by the Research and Development Committee, it passes into the hands of the department concerned for action.

The number of staff members employed on O.R. under the supervision of the director of research has been kept small. At present, there is one senior man in immediate charge, assisted by three others, two of whom are at present concentrating on fuel economy and one on the study of causes of traffic delays on the streets. All are honor graduates. The senior man took the Cambridge Mechanical Science Tripos. This type of "mixed" training in engineering, physics, and mathematics is found to be very suitable for O.R. work. Two of the others are also Cambridge men in physics and engineering respectively, and there is one Oxford man with a physics degree who also has mathematical leanings. Statistical advice is obtainable as required from three honors graduate statisticians on the economics, statistics, and planning side of the department of the chief development and research officer. These man are available to give help on any problems in London Transport upon which expert statistical guidance is required. In addition, both the director of research and the chief development and research officer take a close interest in the work.

5.3 AN EXAMPLE OF THE USE OF ROUTINE DATA

A postwar example is the study of the electrical energy consumption of trains. The departments concerned have compared the rate of energy consumption month by month with the corresponding months of the previous year. Occasionally, increases in consumption have given rise to investigations, usually with inconclusive results. At the instigation of the railway operating department, an O.R. team was set up to study the factors affecting energy consumption, with a view to recommending economy measures.

The relationship between energy consumption and average speed can be calculated, but it was also shown by calculation that energy consumption depends very much on how the motormen drive their trains. Thus, it is not possible to predict, on theoretical grounds alone, what will be the effect of a change in operating practice, such as scheduled speed, or a change in rolling stock characteristics, such as rate of acceleration or braking. Accordingly, it was necessary to study the actual service results of the operating or engineering changes that had been made from time to time. The monthly figures for each line for a period of six years were analyzed by means of "analysis of covariance," which showed that a large part of the variation from month to month was seasonal and was related to average atmospheric temperature for the month. Removal of these purely seasonal variations left some residual variations and a number of significant changes in the level of consumption, some of which could be related to alterations in schedule speed and other known changes. This analysis is being continued as a means of keeping energy consumption under continuous review.

Arrangements were made for hourly readings of the energy consumed and of the number of trains run on a section of one line. These data were found to be related by a multiple regression formula of the following form:

$$U = a + bP + \frac{c}{I}$$

where U = units per car mile
P = proportion of car mileage

run by short trains (of 4 cars instead of 7)

I = intensity of service (car miles run per hour)

and a, b, and c are constants.

This result has assisted in the interpretation of the effects of changes in the service provided.

5.4 AN EXAMPLE OF A PLANNED EXPERIMENT

Although, as in the example described, sufficient data may in some cases be obtainable from routine records and observations of day-to-day operation, it is commonly found that an experiment is necessary to provide essential information. In recent years, there have been important developments in the design of experiments which insure that the results can be subjected to statistical analysis and an assessment of their significance. One such design—the "Latin Square"—has been used recently in experiments to measure the effect of driving technique on the fuel consumption of a bus. Basically, the answer required was the difference in terms of fuel consumption between the two styles of driving known as "steady" and "fluctuating" (in relation to the use of the throttle) at 20 m.p.h. and at 30 m.p.h.

In order to assess the significance of any statistical difference found, it was necessary to carry out a number of observations at each speed. It was also desired to know how the result would be affected by using different buses, different drivers, and different loads. In this case, four highly experienced drivers and four vehicles, especially selected for consistency of fuel consumption, were employed as being the minimum required for reasonably reliable results. The obvious plan was to have each driver drive each bus at each loading, at both speeds and with both styles of driving. But this plan was rejected on grounds of time and expense and also because of possible variations in weather during the four days the test would have lasted. The following plan enabled the tests to be completed in one day and gave the greatest accuracy in measuring the effects of the two most important factors—namely, the two speeds and the two styles of driving.

Scheme for the 64 runs made to determine the fuel consumption in the following four conditions:

20 m.p.h. and fluctuating use of accelerator (denoted by w)
20 mp.h. and steady use of accelerator (denoted by x)
30 m.p h. and fluctuating use of accelerator (denoted by y)
30 m.p.h. and steady use of accelerator (denoted by z)

Sixteen runs were made at each condition according to the scheme shown below, known as a Latin Square.

To overcome the effects of gradual changes in atmospheric temperature and engine temperature during the day, the order in which the runs in conditions w,

	Buses			
Drivers	*A*	*B*	*C*	*D*
a	Load 1	Load 2	Load 3	Load 4
b	Load 2	Load 1	Load 4	Load 3
c	Load 3	Load 4	Load 1	Load 2
d	Load 4	Load 3	Load 2	Load 1

x, y, and z were made was altered systematically as follows:

Bus A	with Driver a	and Load 1
B	" " c	" " 4
C	" " d	" " 2
D	" " b	" " 3

(Simultaneously made runs in the order w, x, y, z.)

The vehicle/driver/load combinations were then changed in accordance with the above scheme to: $Ab2$, $Bd3$, $Cc1$, $Da4$, and runs were made in the order x, w, z, y. After another change: $Ad4$, $Bb1$, $Ca3$, $Dc2$ made runs in the order y, z, w, x. And finally, $Ac3$, $Ba2$, $Cb4$, $Dd1$ made runs in the order z, y, x, w.

The results were analyzed by means of the recognized statistical procedure known as the "analysis of covariance." The experiment gave 16 determinations of the fuel consumed at each speed and style of driving. There was some variation within each set of 16 observations, but, by virtue of the design adopted for the experiments, it was possible to estimate how much of this variation was due to systematic differences between the drivers, the vehicles, and the loads carried. Fuel consumption might also have been related to fuel temperatures and to measured average speed, which varied a little even though the speed and style of driving were specified and adhered to as closely as possible. Thus, with any one style of driving, there were five definable sources to which the variations in fuel consumption might be attributable. Where any of these five sources of variation could be shown to be significant, that amount of variation was extracted from the total, leaving a "residual" or experimental error. It will be seen that great care was taken in designing this experiment to insure that the experimental error was as small as could be contrived. Without such precautions, the results might well have been inconclusive.

5.5 AN EXAMPLE OF PLANNED SERVICE TESTS

Frequently, the number of factors is small and it is desired to find by trials under service conditions an answer to such a simple question as: "Does an increase in fuel injection pump setting on a bus increase or decrease fuel consumption in service?" In this type of experiment, the fuel pump setting can be altered at will and the same vehicles can be run for a period at each setting. It would not be sufficient, however, to make the alteration and to observe simply the change in fuel consumption, since weather and traffic conditions may change at the same time. Therefore, two groups of buses were used. The pumps of one group were at "high," and the others at "low." Both groups were operated for a week. The settings were then altered from "high" to "low" and from "low" to "high," for the next week's operations. This cycle was repeated three times. The analysis of variance of these results, although similar in principle to that described above, was complicated by the greater number of sources of variation—for example, physical differences between the groups of buses and differences between the two constituent weeks of each "cycle." It so happened that only two of these effects proved to be significant—namely, fuel pump setting and differences between cycles. The former result confirmed that the "low" setting was slightly more economical. The second result showed that, as time went on, the fuel consumption increased, presumably because of seasonal changes in traffic and weather. The magnitude of this second effect was that a simple "before and after" experiment could have given a "no difference" answer, if the "high" pump setting had been tested first.

In cases where the experimental feature cannot readily be changed from bus to bus, this "cross-over" design cannot be used. Two chosen groups of buses, similar in all but the experimental feature, must then be compared. The precautions must then be more stringent, involving an interference with the normal allocations of buses to their daily duties. Operational research tries to interfere as little as possible with day-to-day operations, and this latter type

of experimental design is avoided whenever possible.

6. AN APPLICATION OF OPERATIONS RESEARCH IN CERAMICS MANUFACTURING, O. W. HAMILTON

6.1 PERSON IN CHARGE OF O.R.

Holds degrees in Electrical Engineering and in Industrial Statistics from Massachusetts Institute of Technology, with additional courses in educational psychology, accounting, and economic statistics. Had wartime service as radar officer. Since 1947, has had broad experience in management Quality Control, market research, industrial statistics, production planning in chemical processing, the manufacture of railroad and automobile parts and timing instruments. Is now Director, Operations Research, for the United States Time Corporation.

6.2 ORIGIN OF JOB

The study had its beginning when a chance remark was made to the O.R. analyst by the chief project engineer, who had been working two years on the development of the project herein described. The project was to develop a ceramic filtering element with specifications (1) that no foreign material in the solid state with a cross-dimension larger than 0.0005 inches should pass, and (2) that the flow of a liquid through the element should not be below 65 gallons per hour.

Working with different mixes of material and alternately with a pilot kiln and a full-scale kiln, the chief engineer and his co-worker, a ceramics engineer, had developed what they thought would be an acceptable product. However, although it met the specification for passing a solid, at certain times a very large percentage of the elements failed to meet the lower bound of the flow specification. More than a year had been spent in trying to discover the cause or causes of variation. The rejects were re-run through the kiln, so that a total loss was not sustained. However, this project, which was started on the premise that it would be a very profitable sideline, had, after two years, proved to be very costly. The company's president was on the verge of throwing the whole project overboard, in favor of a less potentially profitable line. In a discussion, the chief engineer passed this information along to the O.R. analyst, who, in turn, asked that he be given a try at studying the over-all technical operations. The engineer, rather startled, asked what special qualifications the O.R. analyst, who was neither a ceramist nor a chemist, had for making a full-scale study.

6.3 PLANNING

The immediate job was to persuade the chief engineer—a job that took three weeks. During this time, the chief described the process, which could be divided into five distinct stages. The fourth stage was the earliest one at which results could be measured. The O.R. analyst described several experimental designs for variance analysis and for correlation analysis. Particular stress was put on analysis of variance designs which would incorporate several stages of the process in one experiment.

At this point, the chief engineer said that it would be impossible to carry through with such a study because the company would not consent to giving out the chemical and mix formulae. The analyst quickly interjected that it would not be necessary for him (the analyst) to delve into formulae and that all that was necessary was for the chemist to make up different batches or mixes of material which would be labeled "batch one," "batch two," and so on. Thus the major hurdle was cleared in selling the program.

The over-all technique described appealed to the chief, especially since the problem had so far been attacked one stage at a time.

6.4 FORMING THE TEAM

The next step was to "sell" the works manager, who was a ceramics manufacturer of long and reputable standing. At first, he did not favor further experimenting, because a considerable sum of money had been spent, and, also, he had told the president that the project would be disbanded. The works manager had been very close to this project from its inception and had contributed many suggestions, drawing from his technical knowledge of ceramics and from his knowledge of manufacturing "know-how." When the works manager conveyed the impression that one man, carrying on alone with the project, would not be able to accomplish much, the O.R. analyst proposed that the project be carried forward under the aegis of a team composed of the works manager, the chief engineer, the ceramics engineer, a technician, and the analyst. The analyst would be responsible for experimental designs and the mathematical analysis of data. At no time would any particular phase of the experiment be carried out unless all members of the team understood its purpose and concurred in the experiment. The works manager had visions of further experimentation extending for a year or more, but when the analyst commented that the experimental designs should be completed within a month, the manager consented to go forward with the project, but not until the chief had said that no mix secrets would be divulged.

6.5 DETAILS OF THE PROCESS

The five stages of the process are as follows:

1. Mixing (Banbury Mixers). In the mixing operation, the ingredients as well as the length of time of mixing can be varied.

2. Molding. The mix is placed in a mold, which is then compressed by a hand press machine, each machine being controlled by one operator.

3. Baking. The molded element is allowed to bake in an oven at low temperature, until dry, or until the element is "set."

4. Kiln "Firing." After the molding operation, the filter elements are placed in Carborundum boxes approximately 6 inches wide by 12 inches long by 4 inches deep; one box containing 45 filter elements, five along the width and nine along the length. Filters remain in the box through the drying process and through kiln "firing." As shown in Fig. 15.5 for the kiln "firing," boxes of filters are stacked on a wagon, ten boxes per layer, seven layers high. All boxes stacked one above the other form a tier. Facing the front of the wagon, one would see two tiers of boxes placed end to end; facing the side of the wagon, one would see five tiers placed side to side. After the wagon is loaded, it passes through the tunnel-like kiln, entering at low temperature and gradually reaching the highest temperature in the center of the kiln; then the temperature gradually decreases to the opposite end of the kiln. The contents of the kiln are always changing, so that on one trip a wagonload of filters may have immediately in front of it a wagonload of pottery, and in the immediate rear may be placed a wagonload of ceramic insulators. While in the kiln a certain ingredient "burns" out of the filter element, leaving it porous. When filters finish the firing stage, they may be tested for the flow characteristics.

5. Coating. A very thin substance is sprayed onto the filter to give it a glazed surface finish. This process causes a reduction in the rate of flow and forms the basis for a correlation analysis. The variables are rate of flow before coating, x, and rate of flow after coating, y.

6.6 PLANNING THE EXPERIMENTS

The main planning meeting was attended by the works manager, the chief engineer, a shop technician, the ceramics engineer, and the O.R. man. The latter described analysis of variance as a means of studying main

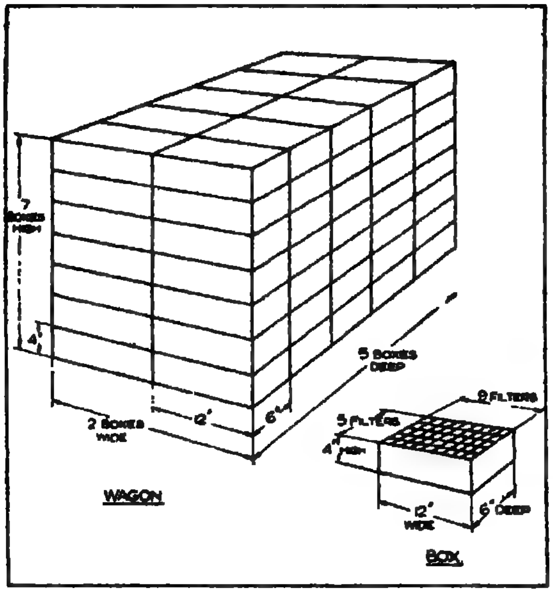


FIG. **15.5** ARRANGEMEMENT OF FILTERS, BOXES, AND WAGONS IN FIRING OF CERAMIC FILTERS.

causes of variation as well as interactions between the main factors; also, he commented briefly on a general factorial design for studying the first four stages of the process. The chief engineer then said that he saw no merit in including either the drying stage or the molding stage, because he felt that these stages contributed nothing to variation; they were formation stages in which no ingredient was added to or subtracted from the filter element. The works manager agreed, but remarked that from his observations he had noticed a great deal of difference in the way operators in general performed. He agreed that there was no way to control drying, which was an interim in the process in which the filters acquired a "set." The O.R. man then suggested that an analysis be made on operators and molding, with all material for the experiment coming from the same mix. Everyone agreed, and the meeting was adjourned for a period of five days while the tests were performed.

6.7 RESULT OF OPERATOR TEST

The operator test was a simple analysis of variance with a number of replications for each of five operators. No significant difference was found. The results were discussed at the next group meeting, at which time the main experimental design was presented.

6.8 MAIN EXPERIMENTAL DESIGN

With general group agreement, and with no supporting evidence that molding and drying affected variation, the second meeting was devoted to a discussion of a proposed four-way analysis of variance.

As mentioned, a box contains 45 filter elements arranged with five filters along the width of the box and nine filters along the length of the box; thus the box became the controlling factor for a factorial design. By using all five filters in a section across the width of the box, the study could incorporate five distinct batches; but four batches ($B1$ through $B4$) were used because of the limited physical capacity of the mixing room. Three sections within the box, the extreme opposite ends and the center, were used. In each case, $S3$ indicates the innermost section of box—i.e., the section near the centerline of the wagon; $S2$ indicates the center section of the box; and $S1$ indicates the outermost section of

TABLE 15.3 FLOW CHARACTERISTICS OF A LIQUID THROUGH FILTER ELEMENTS (Readings are gallons per hour minus a constant)

L1

	T1			T2			T3			T4			T5			T6		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
B1	63	−98	−115	50	−14	−79	67	−15	−25	−5	−52	−160	15	−26	−66	65	21	2
B2	32	21	−88	46	5	−16	38	52	1	65	−68	−60	20	−18	−30	87	43	−33
B3	5	−52	−96	15	59	−55	83	54	−8	71	−53	−100	93	−10	−43	25	5	−7
B4	16	52	−69	28	−20	−16	50	15	−24	11	−30	−42	64	−28	−39	83	0	24

L2

	T1			T2			T3			T4			T5			T6		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
B1	50	17	0	44	18	−4	86	80	15	21	31	26	66	93	33	116	50	38
B2	47	90	13	89	47	28	102	6	−9	40	8	17	30	36	1	97	51	67
B3	56	2	24	40	0	1	45	10	25	29	70	24	29	41	11	64	85	84
B4	108	12	−8	20	−10	110	44	108	44	13	41	29	68	38	3	80	30	3

L3

	T1			T2			T3			T4			T5			T6		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
B1	67	52	50	41	40	35	118	64	50	65	40	52	106	46	37	67	50	28
B2	36	30	21	58	16	24	66	35	85	−4	6	75	50	44	50	58	134	61
B3	15	14	62	83	55	64	33	30	45	7	36	38	119	36	−4	93	44	72
B4	17	−16	15	48	57	35	100	18	7	20	29	36	0	22	33	44	20	50

L4

	T1			T2			T3			T4			T5			T6		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
B1	50	21	66	104	111	63	143	74	69	65	29	21	63	69	47	74	70	69
B2	108	30	84	55	38	29	52	55	69	34	8	11	32	46	15	30	23	50
B3	83	31	31	30	36	48	44	58	32	16	25	6	51	85	8	69	34	23
B4	151	78	36	36	40	24	80	131	42	21	54	4	52	39	80	105	14	33

TABLE 15.3 (*Continued*)

L5

	T1			T2			T3			T4			T5			T6		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
B1	86	71	51	94	26	21	64	80	45	53	31	35	55	33	71	33	45	46
B2	70	63	64	50	74	124	117	56	64	111	14	52	34	22	52	126	61	61
B3	119	9	4	41	81	52	80	62	10	32	46	46	23	46	75	72	42	94
B4	23	19	8	86	29	33	46	64	135	32	16	31	37	86	15	50	4	57

L6

	T1			T2			T3			T4			T5			T6		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
B1	56	49	46	25	80	78	75	71	132	26	28	53	50	50	74	71	41	67
B2	50	46	14	48	81	131	72	105	65	45	40	23	34	30	146	73	89	59
B3	107	56	16	43	25	26	30	122	37	56	53	18	129	44	32	34	66	78
B4	70	45	21	81	−20	0	46	70	18	37	30	0	52	40	23	23	46	35

L7

	T1			T2			T3			T4			T5			T6		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
B1	54	18	38	8	13	1	65	35	109	22	60	72	41	8	30	32	73	15
B2	86	15	10	36	50	63	127	107	31	84	26	64	22	50	65	54	21	42
B3	28	21	33	50	88	−3	71	85	29	70	5	44	14	3	35	34	36	35
B4	39	16	35	64	50	23	50	4	56	9	30	21	10	2	29	50	5	63

TABLE 15.4 ANALYSIS OF VARIANCE TABLE

Source of variance	Degrees of freedom	Sums of squares	Mean squares	F	F. 05
BETWEEN BATCHES (B)	3	105.54	35.18	4.39	3.05
BETWEEN LEVELS (L)	6	1697.07	282.84	35.29	2.15*
BETWEEN TIERS (T)	5	568.12	113.62	14.17	2.27*
WITHIN BOXES (S)	2	660.62	330.31	41.22	3.05*
B × L INTERACTION	18	321.09	17.83	2.22	1.66
B × T INTERACTION	15	79.74	5.31	.63	1.72
B × S INTERACTION	6	24.83	4.13	.51	2.15
L × T INTERACTION	30	366.03	12.20	1.52	1.53
L × S INTERACTION	12	710.95	59.24	7.39	1.81*
T × S INTERACTION	10	100.16	10.01	1.25	1.88
B × L × T INTERACTION	90	652.02	7.24	.94	1.35
B × L × S INTERACTION	36	354.25	9.84	1.22	1.49
B × T × S INTERACTION	30	310.34	10.34	1.29	1.53
L × T × S INTERACTION	60	440.19	7.33	.91	1.40
RESIDUAL	180	1442.39	8.01		
TOTAL	503	7833.40			

box—i.e., the sections near the kiln wall. *L*1 indicates the bottom layer on the wagon, and *L*7 indicates the top layer. *T*1 and *T*2 are the two tiers on the front end of the wagon; *T*3 and *T*4 are the two tiers in the center of the wagon; *T*5 and *T*6 are the two tiers on the rear end of the wagon. The scheme for the analysis of variance was therefore as follows:

Main effects:

Between Batches (*B*1 through *B*4)
Between Layers (*L*1 through *L*7)
Between Tiers (*T*1 through *T*6)
Within Boxes (*S*1 through *S*3)
First Order Interactions:
Batch-Layer Interaction $B \times L$
Batch-Tier Interaction $B \times T$
Batch-Box Interaction $B \times S$
Layer-Tier Interaction $L \times T$
Layer-Box Interaction $L \times S$
Tier-Box Interaction $T \times S$
Second Order Interactions:
Batch-Layer-Tier Interaction $B \times L \times T$
Batch-Layer-Box Interaction $B \times L \times S$
Batch-Tier-Box Interaction $B \times T \times S$
Layer-Tier-Box Interaction $L \times T \times S$
Residual: $B \times L \times S \times T$

The works manager questioned the necessity for studying variance within a box. After all, he argued, a box holds only 45 filters as against a wagon capacity of between 3,000 and 4,000 filters. The O.R. man answered by saying that all parts of the wagon could be analyzed; besides, a remark by the technician that at times he had noticed a very great difference in flow for filters within a box had convinced the O.R. man that a very minute study was in order. No further objection was voiced, and the group accepted the experimental design.

The scheme of the design may be seen in Table 15.3. Table 15.4 shows the calculated results.

6.9 CONCLUSIONS DRAWN FROM ANALYSIS OF VARIANCE TABLE 15.4

In the last column of Table 15.4 are shown F-values for 5 per cent levels of significance. The values with asterisks are also significant at the 1 per cent level. As a basis for taking action, we have selected only those values which are significant at the 1 per cent level. We note, then, that the items which vary significantly from that normally expected are Between Levels, Be-

tween Tiers, and Within Boxes for main effects, and one First Order Interaction —namely, Layer-Box Interaction.

The important question raised at this point was what could be done to reduce the harmful conditions.

First, it was noted that flow values are lower on almost all filters which are placed in sections 3 ($S3$) within the box —that is, in sections along the center line of the wagon. The works manager said that this was because insufficient oxygen was reaching the inside sections, and that the condition could be remedied by leaving a small air space between the ends of the boxes, which were formerly abutted along the centerline of the wagon. This suggestion was acted on immediately.

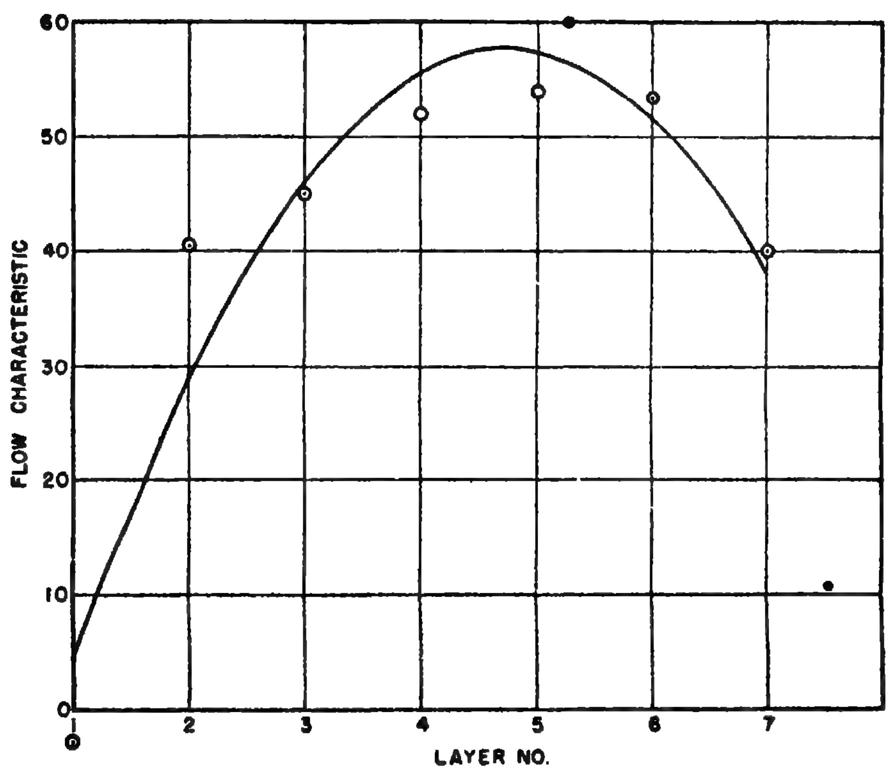
Second, it was noted that there is an abnormal condition between tiers, with the greatest difference between tiers on the front end of the wagon and tiers on the rear end of the wagon. The conclusion here is that the difference is caused by differences in the heat-absorption qualities of different materials loaded on wagons in proximity to the filter wagon; the conclusion was to place the filter wagon between wagons whose contents are homogeneous.

Third, a significant difference was noted between layers. An examination was therefore made of the variation in flow characteristic (averaged over all tiers) and layer number. The results are shown in Fig. 15.6. The curve shown is the best-fitting parabola. It will be seen that the flow characteristic is low on the bottom layer, increases to a maximum at the center, and decreases at the top.

There is a significant difference, at the 5 per cent level, between batches. Batch B3 seems to be the one out of line in both average value and range. The decision was made not to use the formula for B3, since it was the costlier of the four batches used.

It is believed that the abnormal layer-box interaction was significantly reduced by selected layer firing and by provid-

FIG. 15.6 RELATIONSHIP BETWEEN AVERAGE VALVE OF FLOW CHARACTERISTIC AND LAYER NUMBER OF BOX DURING KILN FIRING.



ing an air space between boxes. However, no chance arose for testing this conclusion.

6.10 CORRELATION ANALYSIS OF FLOW CHARACTERISTIC BEFORE COATING VS. FLOW CHARACTERISTIC AFTER COATING

The purpose of the correlation analysis was to determine the minimum for the uncoated filter so that the finished (coated) filter would meet the minimum of 65 gallons per hour.

A sample of 100 filters was selected, and each filter was flow-rated, uncoated—that is, at finish of stage 4. The 100 filters were then coated and flow-rated again. The scatter diagram for the data is shown in Fig. 15.7.

From Fig. 15.7 it can be seen that the relationship between uncoated and coated filters is linear. The equation of regression is

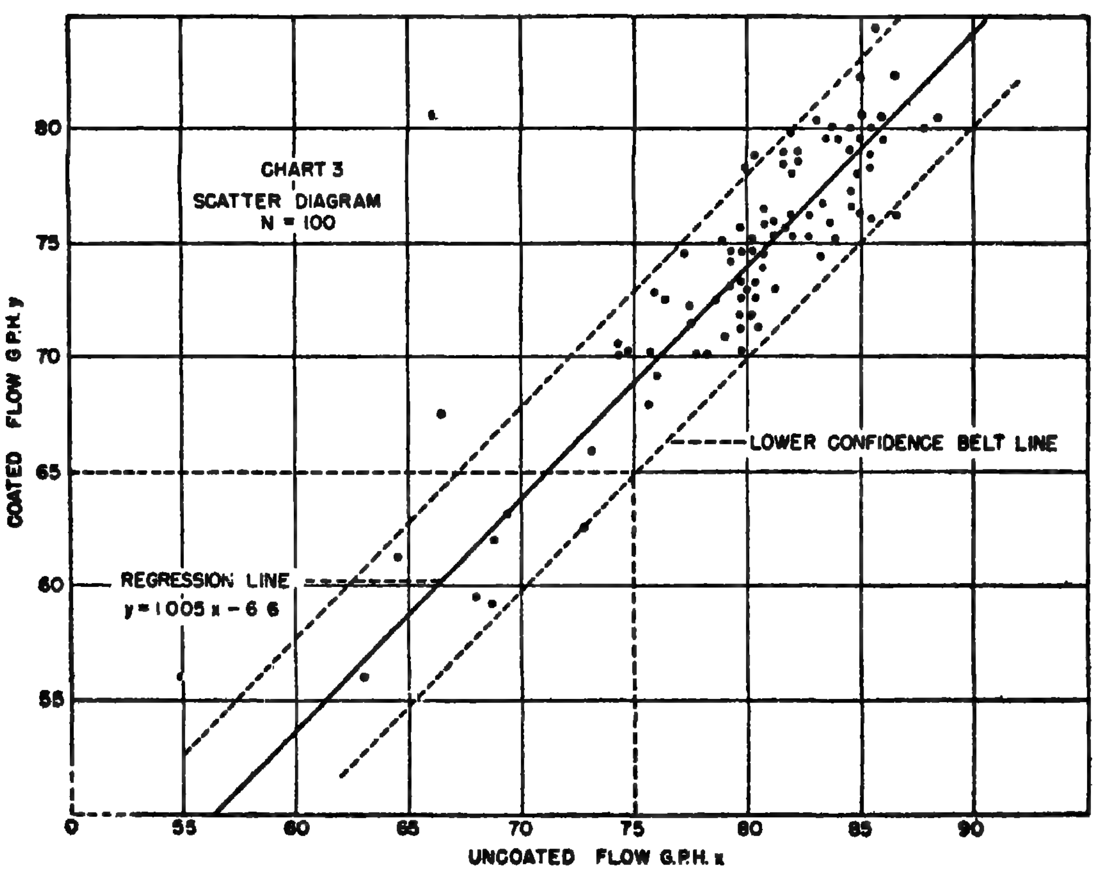
$$y = 1.005x - 6.6$$

where y is the coated flow, and x is the uncoated flow. The correlation was calculated to be $r = 0.9549$, so that $r^2 = 0.912$, and therefore 91.2 per cent of the variability in coated flow can be explained by the variability in uncoated flow.

Thus, on the average, filters lose 6.6 gph in the coating process. But, in order to calculate the minimum flow for the uncoated filter, we utilize the standard deviation about the regression line; but, in turn the standard deviation is calculated from the variance, v_e, of the regression line.

$$\begin{aligned} v_e &= (1 - r^2)S(y - \bar{y})^2/(N-2) \\ &= (0.088)(4157.18)/98 \\ &= 3.74 \\ \text{s.d.} &= (v_e)^{\frac{1}{2}} = 1.934 \end{aligned}$$

FIG. 15.7 RELATIONSHIP BETWEEN FLOW CHARACTERISTICS OF UNCOATED AND COATED FILTERS.



For an approximate 95 per cent confidence belt about the regression line, we would have parallel lines (1.96) (1.934) $= 3.8$ units (gph) vertically above and below the regression line. By extending a line parallel to the x-axis from the point on the y-axis at $y = 65$ gph to the lower confidence belt line, and by extending a perpendicular line from the point on the lower confidence belt line to the x-axis, we see that the x-axis is touched at $x = 75$ gph. Thus, the minimum uncoated flow should be about 75 gph.

6.11 GENERAL CONCLUSIONS

Briefly, the conclusions reached by the operations research team were as follows:

1. There is no abnormal effect on the flow characteristic of filters as a result of operator differences.*
2. Batch or mix differences, as far as it was physically possible to vary, do not abnormally affect the flow.
3. The abnormal effects were due to positioning of the filter within the kiln wagon; the greatest were due to the main effect of position within a box. The effect of layer position was found to be significant; it was also found that the other contents of the kiln affect variability.

Although the technical people who had developed the filter project were very competent, each in his own field of specialty, a comprehensive program for properly studying the over-all technical operations was lacking; in particular, a program was lacking for studying the relationships and interaction between and within stages of the operations.

6.12 RECOMMENDATIONS

Most of the recommendations here noted were put into effect long before the study was completed. The team recommended:

1. That an air space be provided between the boxes, which were formerly abutted along the centerline of the wagon.
2. That the bottom layer on the wagon not be utilized for firing filters.
3. That the filter wagon be programed between wagons with homogeneous material as far as possible.
4. That, within the confines of present batch formulae in use, the lowest-cost mixing procedure be used.
5. That the minimum flow for uncoated filters should be 75 gph.

6.13 FOLLOW-UP

About a year after the study, the O.R. man had a chance to talk with the works manager. The report was that, since the recommendations had been in practice, a very, very small percentage of filters had been rejected, and that the cost and technical position had been greatly improved.

7. THE APPLICATION OF SAMPLING TO LCL INTERLINE SETTLEMENTS OF ACCOUNTS ON AMERICAN RAILROADS, PROFESSOR C. WEST CHURCHMAN

7.1 PERSON IN CHARGE OF O.R. WORK

Was trained in symbolic logic and philosophy of science, and has a Ph.D. in philosophy. Has devoted a great deal of effort and writing to the methodology of science and the analysis of concepts, especially in the social sciences. Acted as a mathematical statistician for a U. S. Army Ordnance laboratory during the war, and has written several expositions of statistical methods for research workers. Is now in charge of Operations Research at the Case Institute of Technology, Cleveland, Ohio.

7.2 THE TEAM IN CHARGE OF O.R WORK

This problem was suggested as a possible area of application of op-

erations research during discussion between the Case Institute of Technology and the Chesapeake and Ohio Railway. The problem is being studied by a team composed of members of Case's operations research group and members of the finance department of the C&O. The interest and co-operation of the C&O administration and personnel were largely responsible for the initiation of the project, and their perseverance has carried it to its present stage of development. The C&O personnel are not responsible for any inaccuracies of fact or method that may appear here.

The following persons are or have been involved in the research to date:

One philosopher of science.

One mathematician.

One mathematical statistician.

Two methods engineers, well versed in IBM (punched-card) procedures.

Two auditors of revenue for the C&O Railway.

In addition, other personnel have contributed advice and assistance from time to time. The "team" has never been formalized to the extent of having any official recognition, since it is felt that a formalized team would quickly lead to an "in-group" and "out-group" attitude which would be highly unsatisfactory in the development of the project.

7.3 ORIGIN AND ANALYSIS OF PROBLEM

The American railroads settle accounts between one another at the end of each month by apportioning the total amount paid for the transportation of shipment between the participating railroads. Thus the Squeedunk and Central Railroad initiated a movement at Mihome Town. The S.C.R.R. hauled the freight to Co-op Junction and handed it over to the Tokyo and Northwestern. The T&N continued the haul to Bridal Junction and transferred the freight to the Great Grand and Pacific. The G.G.&P. delivered the freight to the consignee at Yurtown. The consignee at Yurtown paid the G.G.&P. the entire freight charges. At the end of the month, the G.G.&P. must divide this freight charge appropriately and give to the S.C.R.R. and to the T&N their correct proportion.

The innocent bystander might suppose that the meaning of "appropriate" in this connection could be defined in terms of the exact number of miles each railroad hauled the freight. But this would seem very naive to a well-bred railroader. First of all the S.C.R.R. hauls the freight over the Muddy Waters River, and for this the railroad receives an "arbitrary" amount in addition to the computed proportions. The T&N line between Co-op and Bridal Junction is not the shortest route; another railroad has a shorter line between these points. The T&N is reimbursed on a "short line" basis—i.e., on the shortest railroad distance between the points of its haul. Finally, the G.G.&P. hauls in the southwestern territory of the United States, and is given a "boost" rate of an additional 20 per cent.

In general, the computation of the proper "divisions" between co-operative carriers is a complicated process, often involving expert clerical help. If the shipment happens to be "less than carload" (LCL), the total freight amount may be as small as two dollars. Should an expert clerk spend several hours of his time computing the proper division of two dollars between a couple of railroads? Early in the 1930's, when the depression raised problems of efficiency, many of the railroads decided that the use of clerks for LCL divisions was an uneconomical procedure. The solution to the problem consisted of taking a whole year's experience and arriving at a percentage figure. This percentage is then used as a basis of dividing the total LCL freight amounts of shipments in which two or more carriers contribute. Thus a year's experience of the S.C.R.R. and the T&N may be that the S.C.R.R. received 58.26 per cent of the total freight amount of shipments initiated on the T&N, passing through Co-op, and terminating on the S.C.R.R. The total LCL freight amount received for any month of any subsequent year by the S.C.R.R.

of such shipments is now divided on a 58.26 per cent and 41.74 per cent basis. Any percentage may be "checked" at the request of any of the participating railroads.

This solution evidently saves clerical time, but it runs the risk of a loss of financial control. The "experience" of one year may not be the experience of the next, and probably is not the experience of ten years later. But to check a "road-to-road" percentage requires an additional burden on the clerical staff, usually in the form of overtime.

The first problem is: Can sampling methods be used to provide a sufficiently accurate estimate of the road-to-road percentages with a significant reduction in costs?

The next operations research problem is: If sampling can be used, how shall it be installed in the railroad industry with minimum confusion and maximum savings?

7.4 PLANNING THE FIRST TESTS

In order to translate the railroad problem into a sampling problem, consider the nature of the population. The physical items are waybills, on which are recorded the total charges, a waybill number, route, weight, commodity, and so forth. The population of data which interests us is the dollar amounts due to the S.C.R.R. and to the T&N. (For the purposes of simplification, we consider settlements between two railroads only.) These dollar amounts are not shown originally on the waybills and must be calculated.

A number of sampling schemes are possible, including a random sampling in terms of waybill number. But it is now customary for the railroads to punch the waybill information into IBM cards, so that various methods of sorting the total population of physical items can be accomplished cheaply. It is reasonable to suppose that the dollar amounts due each railroad vary directly with the total freight amount. Hence waybills showing a small total charge are probably less important than waybills with larger total charges. This suggests a stratified sampling scheme. The divisions of the strata can be roughly estimated by plotting a histogram of the total freight amounts and making a first estimate of the proper dividing lines.

In general, accuracy will increase if the number of strata is increased. For example, in addition to stratifying the population by total freight amounts, one might also try a commodity stratification, or a stratification by zones on the originating and/or terminating carrier. But each additional stratification increases the cost of handling the items and the consequent risk of inaccuracy.

The first test consisted of determining whether a stratification by total freight amount would alone yield satisfactory accuracy. The histogram of these amounts indicated that most items fall below $10, but that by far the greatest contribution to the dollar volume lies above $10. This relation of item to dollar volume is quite common in industry and might be called the Inverse Dollar Law. The following strata were used as a basis of test:

Total freight amounts between

Group I	\$ 0 and \$ 4.99
Group II	\$ 5.00 and \$ 9.99
Group III	\$10.00 and \$19.99
Group IV	\$20 00 and \$40.00
Group V	over \$40.00

The relative percentages to be sampled in each stratum can be determined by textbook formulae for optimum stratification. Such formulae require the errors of the sample estimates within strata, which will be discussed below. It is not feasible to use the exact percentages recommended by optimum stratification because of the difficulties in drawing the sample. The following "compromise" percentages were used instead:

Group I	5%
Group II	10%
Group III	20%
Group IV	50%
Group V	100%

These percentages can be scaled upward or downward, depending on the recom-

mended amount of sampling in terms of costs and risks. The last group is worthy of comment. In populations of the type under consideration, there will be a long "tail" in the distribution; erratic amounts up to $200 or over may occur. The only feasible procedure seems to be to include all these items, since the cost of sampling depends on the number of items, and the erratic items are not frequent.

The design of the test requires a method of drawing the sample. The waybills are numbered, and, in general, are pretty well scrambled by the time they reach the auditor's office. This situation suggests sampling by ending digits of the waybill number. The Interstate Commerce Commission has sampled carload waybills by this method for the last seven years in estimating various railroad traffic statistics. They have found that, in general, waybills numbered 1 or ending in 01 yield a random sample. Exceptions occur when the agents at stations are given small blocks of waybill numbers (e.g., the agent may number up to 50 and start again). If any doubt as to randomness occurs, the waybills may be selected by a random process on an IBM sorter. If we assume no bias in a systematic sample, the following procedure can be used:

	Waybills ending in
Group I	02,22,42,62,82 (including number 2)
Group II	2
Group III	2 and 4
Group IV	01 to 50 (including numbers 1 to 9)
Group V	any digit

Samples drawn in this manner will yield approximately the percentages given above.

7.5 RESULTS

The results of the test can best be explained by an example. Figure 15.8 is typical. Let ij denote the j^{th} waybill in the i^{th} Group. The column headed $\sum_j X_{ij}$ = actual T&N dollars represents the amounts to be estimated by the sample. That is, if only sampling were used, the $\sum_j X_{ij}$ column would not be filled in, but would be estimated from the rest of the data. We let $\sum_j Y_{ij}$ represent the sums of the actual freight amounts, $\sum_j x_{ij}$ the dollars due the T&N from the sample waybills only $\sum_j y_{ij}$, the freight amounts of the sample waybills.

Thus if sampling were used, we would have $\sum_j Y_{ij}$, $\sum_j x_{ij}$, and $\sum_j y_{ij}$ for each group. We would also have N_i, the total number of waybills, and n_i the number of sample waybills, for each group.

Two methods of estimating $\sum_j X_{ij}$ are commonly used. The first consists of "blowing up" the sample $\sum x_{ij}$ by the re-

FIG. 15.8 TYPICAL RESULTS OF SAMPLING TEST.

Freight amount group	Number of waybills		Total freight		T&N Share		
	Population	Sample	$\sum_j Y_{ij}$	$\sum_j y_{ij}$	$\sum_j X_{ij}$	$\sum_j x_{ij}$	Difference
1	3672	186	$9658.51	$ 488.84	$4252.47	$4306.85	+$54.38
2	818	72	5663.40	497.99	2537.82	2575.19	+37.37
3	395	82	5445.99	1097.57	2506.02	2575.65	+69.63
4	119	51	3148.32	1382.82	1426.66	1421.71	−4.95
5	42	42	2370.54	2370.54	1070.22	1070.22	0
Totals	5046	433	$26,286.76	$5837.76	$11,793.19	$11,949.62	+$156.43

ciprocal of the sample ratio. This "linear" estimate is based on the formula

$$\text{Linear est. of } \sum_j X_{ij} = \frac{N_1}{n_i};$$

$$\sum_j x_{ij} = \frac{1}{\lambda} \sum x_{ij}$$

where λ is the sample ratio. In our case $\lambda_1 = 0.05$, $\lambda_2 = 0.10$, $\lambda_3 = 0.20$, $\lambda_4 = 0.50$, $\lambda_5 = 1.00$. The variance of this estimate would be the variance of $\sum_j x_{ij}$ divided by λ^2.

The other method of estimating is called the ratio estimate, and consists of projecting the sample $\sum_j x_{ij}$ by the ratio of the actual freight amount to the sample freight amount:

$$\text{Ratio est. of } \sum_j X_{ij} = \frac{\sum_i Y_{ij}}{\sum y_{ij}} \sum x_{ij}$$

The ratio estimate has a smaller variance than the linear estimate provided the correlation between X_{ij} and Y_{ij} is large enough. Specifically, let β be the ratio of $\sum_j X_{ij}$ to $\sum_i Y_{ij}$ (i.e., the proportion due to the T&N). Then the ratio estimate is more efficient than the linear estimate provided.

$$\rho_{XY} > \frac{1}{2} \beta(\sigma_{Y_{ij}}/\sigma_{X_{ij}})$$

From the data in Fig. 15.8, Group 1:

$$s_{X_{ij}} = 0.42; \qquad s_{Y_{ij}} = 0.77$$

$$\sum_j X_{ij} = 4252.47; \qquad \sum_i Y_{ij} = 9658.51$$

$$\beta = 0.445$$

Hence, if the ratio estimate is preferable, we should have

$$\rho_{XY} > 1/2(0.445)(0.77/0.42) = 0.40 \text{ (about)}$$

For Group I

$$\rho_{XY} = 0.80$$

which indicates that the ratio estimate is preferable in this case. Similarly, it will be found that the ratio estimate is more efficient in each of the other groups.

The standard deviation of the over-all estimate of $\sum_i \sum_j X_{ij}$ can be obtained by adding up the variances of the estimates of $\sum_j X_{ij}$ for each group (the variance for Group V being zero), and taking the square root of the result. In the case of the study reported in Fig. 15.8, the standard deviation of the ratio estimate of $\sum_i \sum_j X_{ij}$ was \$101.65.

7.6 RECOMMENDATIONS

In order to show that sampling is feasible, some cost estimates are required. The unit of cost is not the waybill itself, but the so-called "station-to-station" combination. All waybills of shipments originating at Station A on the T&N and following the same route to Station B on the S.C.R.R. can be grouped together for purposes of computing divisions of revenue. For the complete count there were 2,512 station-to-station combinations (i.e., roughly one-half the number of waybills). In the sample there were 275 station-to-station combinations. Thus sampling avoids consideration of $2{,}512 - 275 = 2{,}237$ combinations. Suppose (on the conservative side) that on the average it costs 20 cents to consider each combination. The sample therefore saves (0.20) (2237) = \$447.40. The maximum error of the sample would be three times the standard deviation—that is, \$304.95. Thus even the worst possible interpretation of the results indicates that sampling saves money. The saving may seem small, but when one considers that each major railroad may have as many as 2,000 road-to-road percentages to consider, even \$100 savings on each study may add up to tremendous over-all savings.

If one looks at the problem, the advantages of sampling are much greater from the point of view not of maximum error, but of average error. Suppose that any error due to sampling which constitutes a loss to the company is charged directly as loss, whereas any deviation

which constitutes a gain is regarded as "fortuitous" and is not credited in the company's profits. What is the predicted long-run loss under such a policy? If the sampling errors follow a normal distribution with zero mean, then the problem is one of determining the average of all minus deviations. The answer is $\sigma\sqrt{2\pi}$ or about 0.8σ. In our case, σ is estimated by s to be \$101.65, and the average loss is therefore less than \$85. Thus sampling would constitute a large gain over the complete count. As mentioned above, the average savings of the sample over the complete count for populations of this size is about \$450 and the sample error averages only \$41. The sample therefore would save over \$400, and sampling in general would constitute a tremendous gain.

But why should a company regard the "plus" sample deviations as fortuitous? If sampling of accounts becomes an industry policy, what is the expected loss for any one industry? The answer is zero! What governs the size of the sample, then? The only sensible answer seems to be that the sample size should be large enough so that no one month's sample results would "embarrass" the company financially. Even large deviations will "balance out" in the long run. That is, the percentage error approaches zero as the volume in dollars becomes larger and larger. The actual dollar error increases without limit, but the dollar saving of sampling over complete count also increases without limit. Since most large railroads would never be critically embarrassed by LCL sampling losses, we could tolerate a much smaller sample size than the one used in the test.

Those familiar with the mathematical models of operations research will wonder why no cost equation has been set up to determine optimum sample size. The answer is that industry has not yet thought enough in terms of "expected" profits and losses as opposed to "actual" profits and losses. Three possible attitudes have been mentioned that the accountant might adopt with respect to the use of sampling for settling accounts. He might charge against sampling the largest unfavorable error (e.g., three sigma) or the average unfavorable error (0.4σ), or no error, the sample size in the last case being based on the largest tolerable monthly or yearly error.

The third attitude seems most reasonable, and if it were adopted by industry a far smaller sample size could be used. But the first attitude, which is actually the least reasonable, is the one that many auditors of accounts will regard as "realistic." They will want to know how much deviation could occur at the very outside on any one month's trial. As one auditor of revenues said, "I am here to guard against any loss of revenue to the company; if a large unfavorable sampling error occurs, I have failed in my duty to the company." For this reason, it seems wise during the "selling" period to adjust the sample size to the "unreasonable" but actual psychology. As industry becomes used to the very important idea behind sampling, it should also become more and more amenable to the zero loss but minimum monthly-risk philosophy. In any case, sampling may very well establish an entirely new outlook on accounting controls; perhaps "penny accuracy" will be replaced by "dollar risk" properly adjusted to the errors of estimates.

It should be emphasized here that the reduction in volume of items often makes the sample more accurate than the complete count. The sample contains fewer items, and these can be scrutinized more carefully; further, the statistical computations are subject to fewer errors. But this oft-quoted advantage is not nearly so important as the new attitude toward real profits and losses that sampling engenders—namely, what does it cost to keep accuracy at a given level? At this date, we have shown that sampling will work in many industrial settlements. New road-to-road LCL percentages have actually been established between two roads on a sampling basis. But the real operations research job of selling still lies ahead—not merely selling with respect to sampling LCL accounts, but with respect to the many other areas of industrial

operation where sampling is far more efficient than the complete count.

8. OBTAINING MAXIMUM EFFICIENCY FROM A BARBER-COLMAN SPOOLER, ALLAN ORMEROD AND WALTER S. SONDHELM

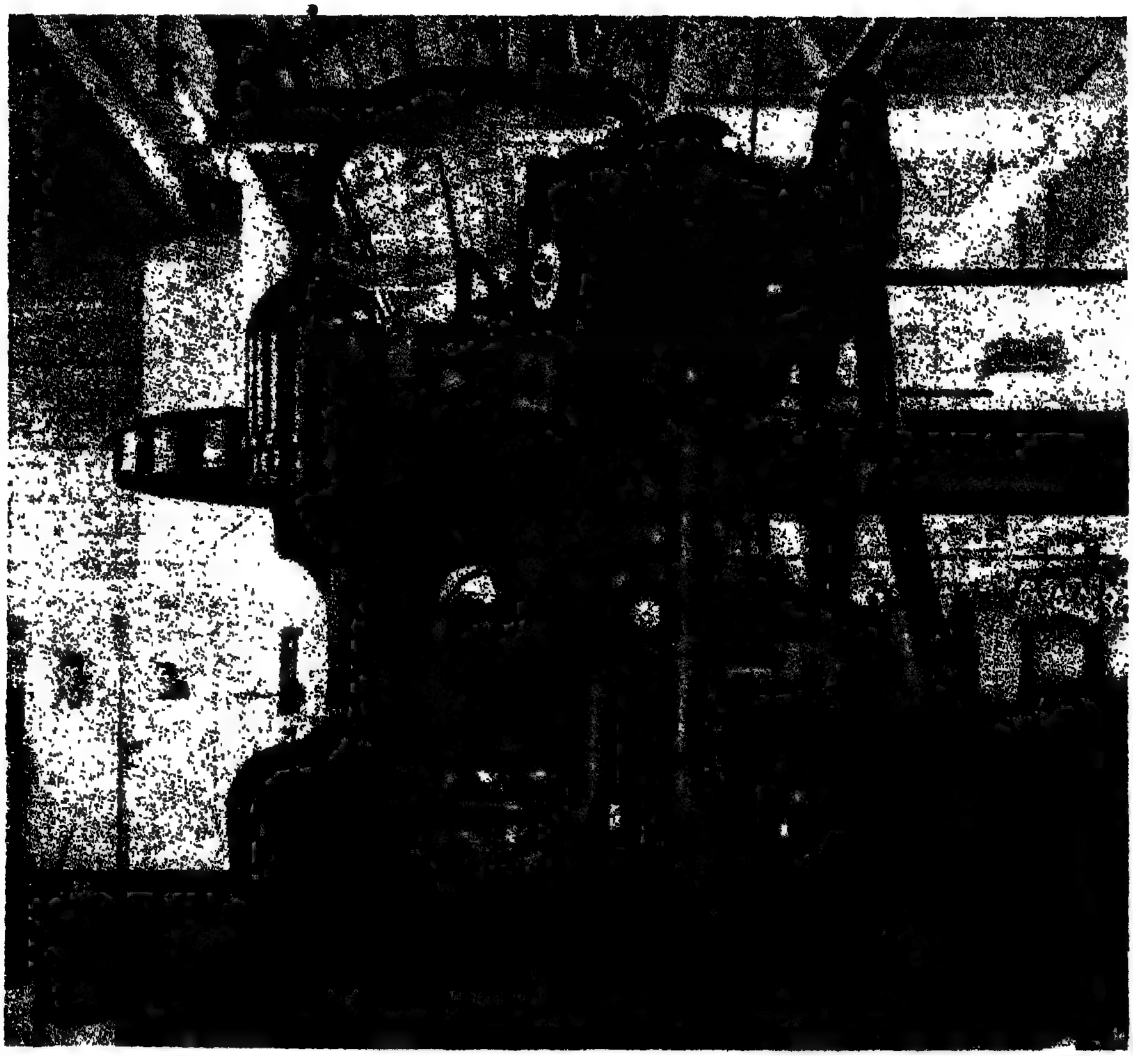
8.1 PERSONS IN CHARGE OF O.R.

Allan Ormerod, an Associate of the Manchester College of Technology in Mechanical Engineering, A.I.Mech.E., and A.M.I.Prod.E., has had experience in both the engineering and cotton textile industries and was formerly Chief Design Officer, Armaments Design Department, Ministry of Supply. He is the weaving manager of Ashton Bros. & Co., Ltd. Walter S. Sondhelm, M.Sc.Tech. (Manchester), A.M.C.T. and A.T.I., is the textile technologist of Ashton Bros. & Co. Ltd. Both authors are actively interested in the improvement of technical knowledge in the cotton industry; both have contributed papers on various aspects of the industry to various societies; and both are members of the Lancashire Section Committee of the Textile Institute.

8.2 ORIGIN OF THE PROBLEM

Through analysis of operating results, the technical management decided that increased output and reduced costs might be obtained by reorganization.

FIG. 15.9 KNOTTER HEAD.



8.3 STATEMENT OF THE PROBLEM AND ANALYSIS: SUMMARY:

(1) To obtain increased output of Barber-Colman spools required for high-speed warping.

(2) To determine the sensitivity of operator hours per pound (weight) and cost to machine size and supply package size.

(3) To obtain conditions where capital elements and direct labor elements of costs could be simultaneously minimized.

(4) To organize spooling quantities and supply packages to approach as near as possible to this optimum.

8.4 DESCRIPTION OF EQUIPMENT

Three views of the machine are shown in Figs. 15.9, 15.10, and 15.11.

A. *Functions*

1. To aggregate a large number of spinning packages (ring tubes or bobbins) onto a package known as a spool in order to present a larger package at the next process.

2. To remove major imperfections from the yarn as received from the spinning room.

B. *Machine particulars and speeds*

1. Bobbin pockets and winding units are situated along both sides of the spooler.

FIG. **15.10** BARBER-COLMAN SPOOLER.

2. Machines varying in size between 90 and 306 winding stations in units of 18 stations are available.

3. A traveling knotter head is driven automatically around a continuous track on top of the spooler; semicircular sections are provided to enable it to turn at each end.

4. The knotter-head linear speed is 90 bobbin stations per minute. It is inoperative for 0.30 minutes at each end of the spooler for its change of direction.

5. After each circuit, the knotter head may be stopped for up to 0.60 minutes.

6. The machine is divided into four "quarters" to enable four types of yarn to be wound simultaneously.

7. Belt conveyors deliver empty and partly empty ring tubes to four separate reject trays at the end of the machine.

C. *Operation particulars* (Fig. 15.14)

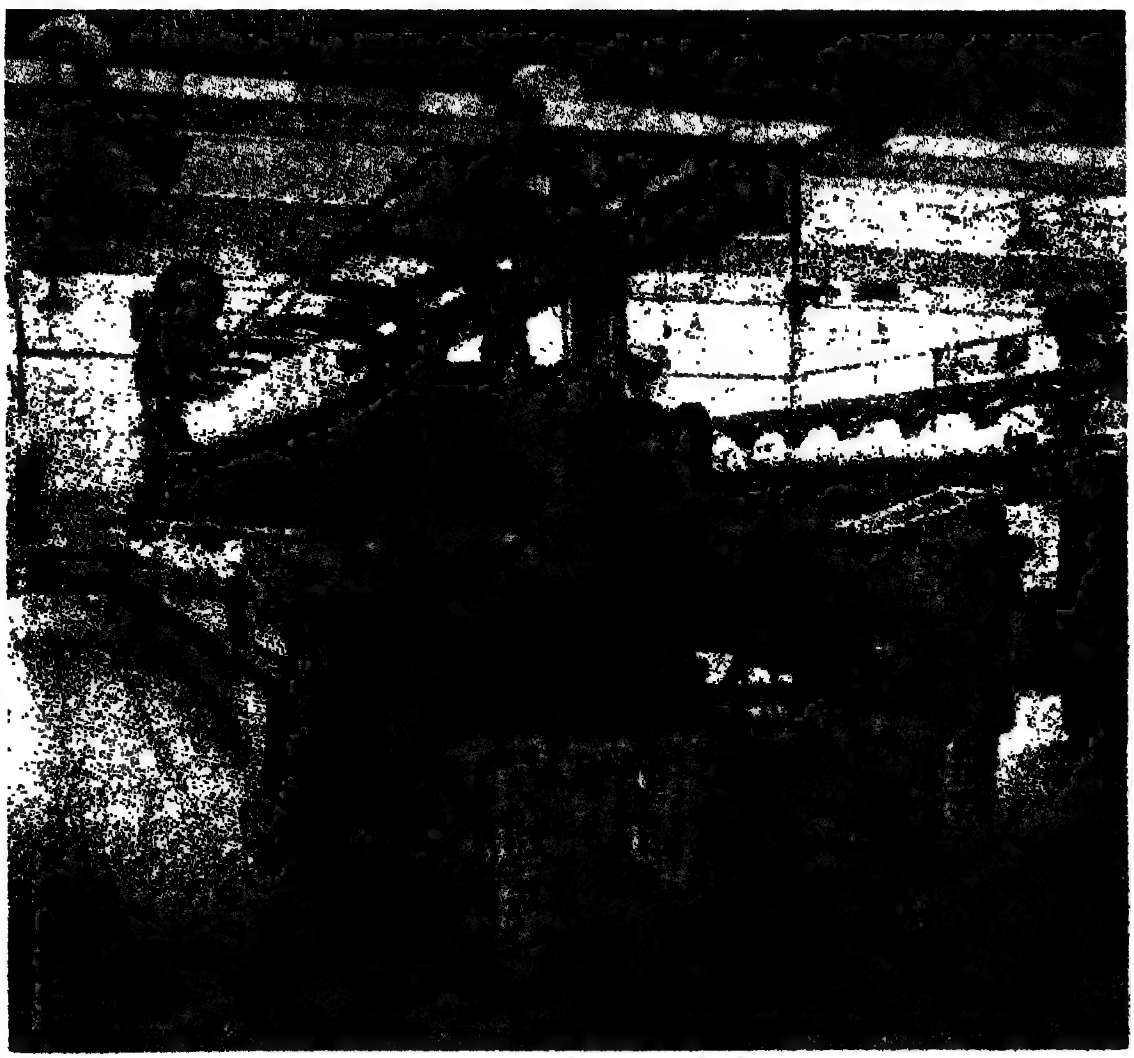
1. *Knotter headstock*

a. Stops rotation of spool.

b. Calipers spool to determine whether spool has reached minimum size.

c. If spool has not yet reached minimum size, it locates the end of the yarn on the spool by pneumatic means, and the end of the newly loaded ring tube by mechanical means; it also ties a weaver's knot and at the same time controls the tension to prevent snarls from forming. At the same time, it transfers the ring tube in the bobbin pocket to

FIG. 15.11 GENERAL VIEW OF BARBER-COLMAN SPOOLER. •



the winding position and lowers the spool onto the winding drum.

d. If the spool has reached the minimum size, it is not tied up to the newly loaded ring tube; the end of the ring tube is left in the locating grip, thus indicating to the operator that the spool is full.

e. When the full bobbin is transferred to the winding position, the bobbin in the winding position is ejected onto the belt conveyor for transport to the reject trays.

2. *Winding*

f. The yarn is wound at a speed of 1200 yards per minute.

g. Several adjacent spools are handled simultaneously by the winding head, resulting in a loss of production equal to 94 yards per knotter-head cycle (7 spools are noneffective during the actual knotting—not circuit—time).

h. The maximum length of package which can be unwound on the spooler depends on the number of its winding stations and the period (maximum 0.60 min.) during which the knotter head is stopped after each cycle.

i. After all the yarn has been wound from the bobbin, or whenever the yarn breaks during the unwinding, the spool is thrown off the winding drum.

j. If the knotter head reaches a station before the package tied during the previous cycle has been wound, the knotter head is stopped and has to be restarted manually.

8.5 ANALYSIS OF THE PROBLEMS

The spooler attendant's duties and standard time in minutes are shown in Table 15.5.

Only one solution of optimum machine size will give maximum operative efficiency for each team complement for a particular spun package content—i.e., count and length. This maximum operative efficiency may occur at a relatively low machine efficiency. Since prime cost is a function of both labor and machine costs, it is clearly desirable to arrive at a solution in which both optimum conditions obtain—i.e., the operator is working consistently at an 80 and the machine is operating with zero dwell and arriving at each winding station for

TABLE 15.5 SPOOLER ATTENDANT'S DUTIES AND STANDARD ELEMENTAL TIMES*

Group element No.	Details of operation	Standard times observed
1.	Take hold of ring tube from supply trough situated below the bobbin pockets, locate the thread, place the bobbin in the bobbin pocket and assemble the thread to locating grip.	0.040
2.	Remove full spool from spool holder, place on trident peg on truck, pick up new "starter core" from truck and place on spool holder.	0.150
3.	Remove truck containing 15 full spools to loading table, slide off tridents onto roller table, and slide off starter cores.	0.400
4.	Sort out empty bobbins from bobbin troughs and place on conveyor.	0.110
5.	Empty tray at frame ends and remove reject bobbins for re-insertion into pockets.	0.020

* Times in minutes and decimals of a minute.

knotting at the precise moment when the previous tube winds off.

For maximum machine utilization:

$$P = 1200\left(\frac{(N-7)}{90} + 0.60D_f + 0.63\right) \quad \text{(i)}$$

where P = ring tube package content in yards
N = number of winding units on the machine
D_f = fractional dwell setting. (Max. setting = 0.60 minutes)

For maximum operator utilization:

$$P = 1200\frac{N}{n}$$

(80 rate time to handle one bobbin and *all* associated functions for that bobbin)

where n = number of spooler operators per machine.
From the basic work study data, the 80 rate time was shown to be:

$$0.84\left[0.04(1+K) + \frac{W_b}{W_s}\left(0.15 + \frac{0.40}{0.15}\right)\right] \quad \text{(ii)}$$

where
W_b = bobbin weight in lb.
W_s = spool weight in lb.
K = a proportionality constant to cover elements 4 and 5 and is found to be 0.08 for a wide range of conditions.

It can be shown that both conditions can be maximized when the following equation is satisfied:

$$\frac{0.00099N^2}{C} - 0.5523n - 0.0111Nn + 0.03632N + \frac{0.0493N}{C} = 0 \quad \text{(iii)}$$

where all symbols are as before and C is the yarn count spooling.

Figure 15 12 shows the optimum combinations of ring tube capacity and machine size (number of spools per machine) for each count in the range 10*s* to 50*s*. Under no other circumstances is it possible to obtain 100 per cent machine utilization and 100 per cent operator utilization.

Viewed from another aspect, a curve was plotted of the corresponding optimum *bobbin content* for a range of counts, each bobbin content corresponding to a particular machine size. An empirical equation was deduced from these curves (one for 3 spooler operators/machine and one for 4 spooler operators/machine).

Where $n = 4$

W, Opt. bobbin wt. (lb.)

$$= \left(\frac{1}{{}_{10}0.0312C + 0.4722}\right) + 0.1855$$

Where $n = 3$

$$W = \left(\frac{1}{{}_{10}0.0272C + 0.5496}\right) + 0.0717$$

8.6 CRITICAL APPRECIATION OF ORIGINAL INSTALLATION

The spoolers originally installed were 126 spooler units winding a package of 0.140 lb. weight and an average count of 15*s* (i.e., approximately 1700 yards). The three operators per spooler were fully utilized but machine efficiency was low, because the spools ran out long before the circuit was completed. Machine efficiencies somewhat lower than 65 per cent were being obtained, because of shortage of length on the ring tube.

Fig. 15.13 shows that 100 per cent machine utilization is obtained at zero dwell condition on a 126-unit spooler on 15*s* counts using a package of 0.19 lb., or approximately 2300 yards. Thus the ring tubes were too small for efficient operation. Figure 15.12 shows that optimum conditions could be achieved with a 126-unit spooler on 16.75*s* counts with a package of 0.165 lb. and 3 spooler attendants per machine. If the existing machine were to be used, an increase in required package size of some 18 per cent was clearly indicated.

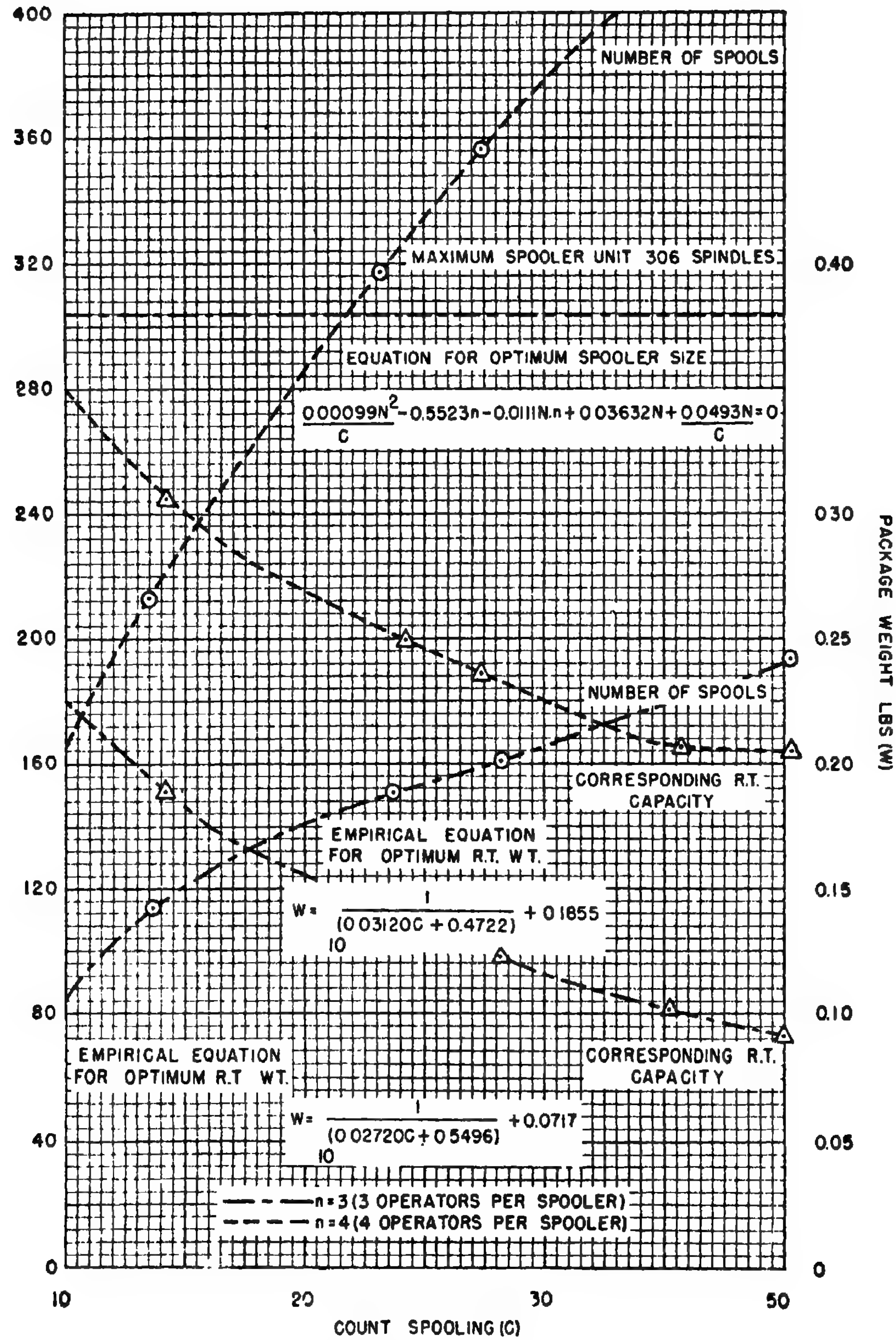


FIG. **15.12** OPTIMUM COMBINATIONS OF RING TUBE CAPACITY AND MACHINE SIZE.

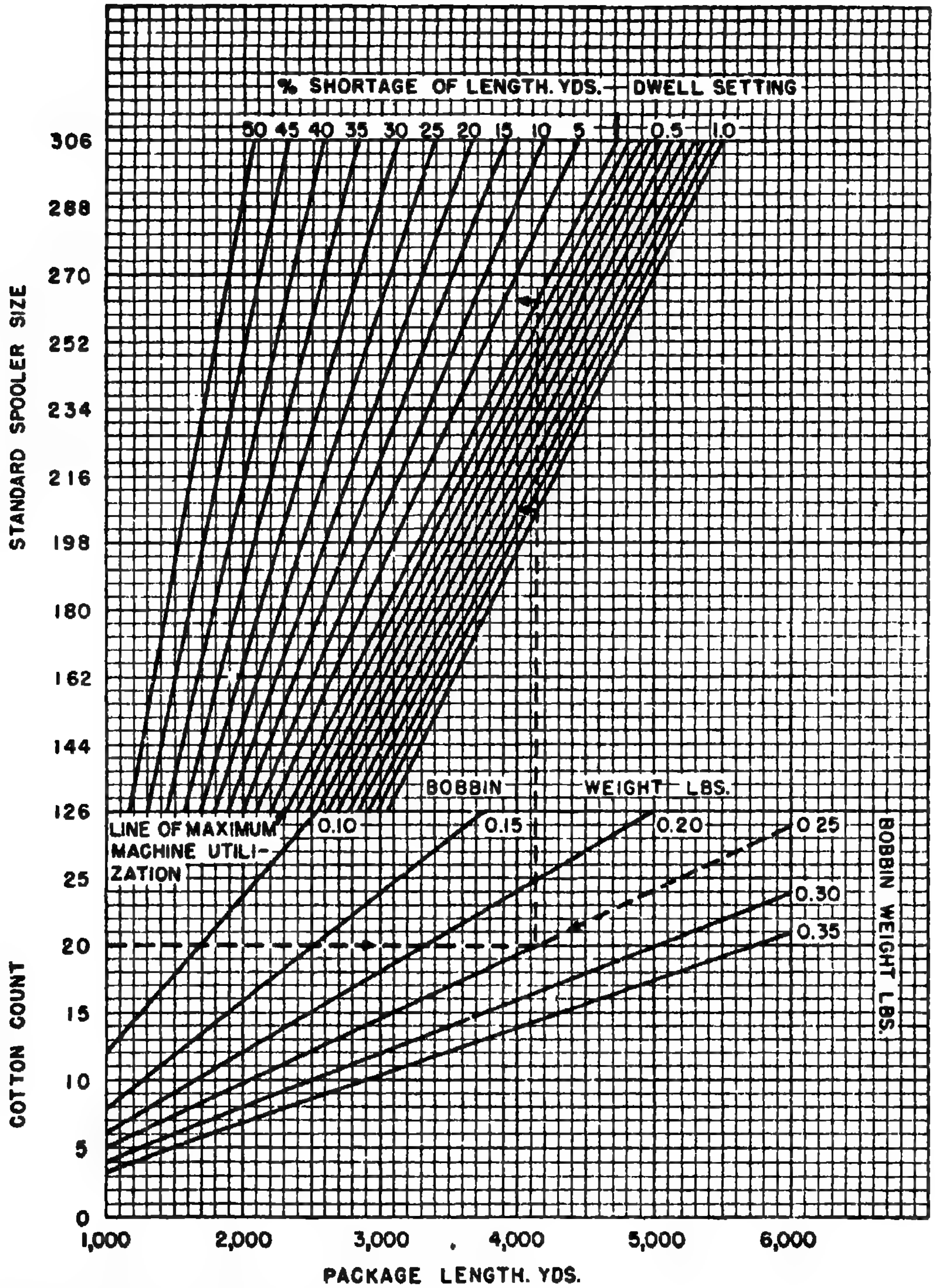


FIG. **15.13** CHART FOR MAXIMUM MACHINE UTILIZATION OF BARBER-COLMAN SPOOLER.

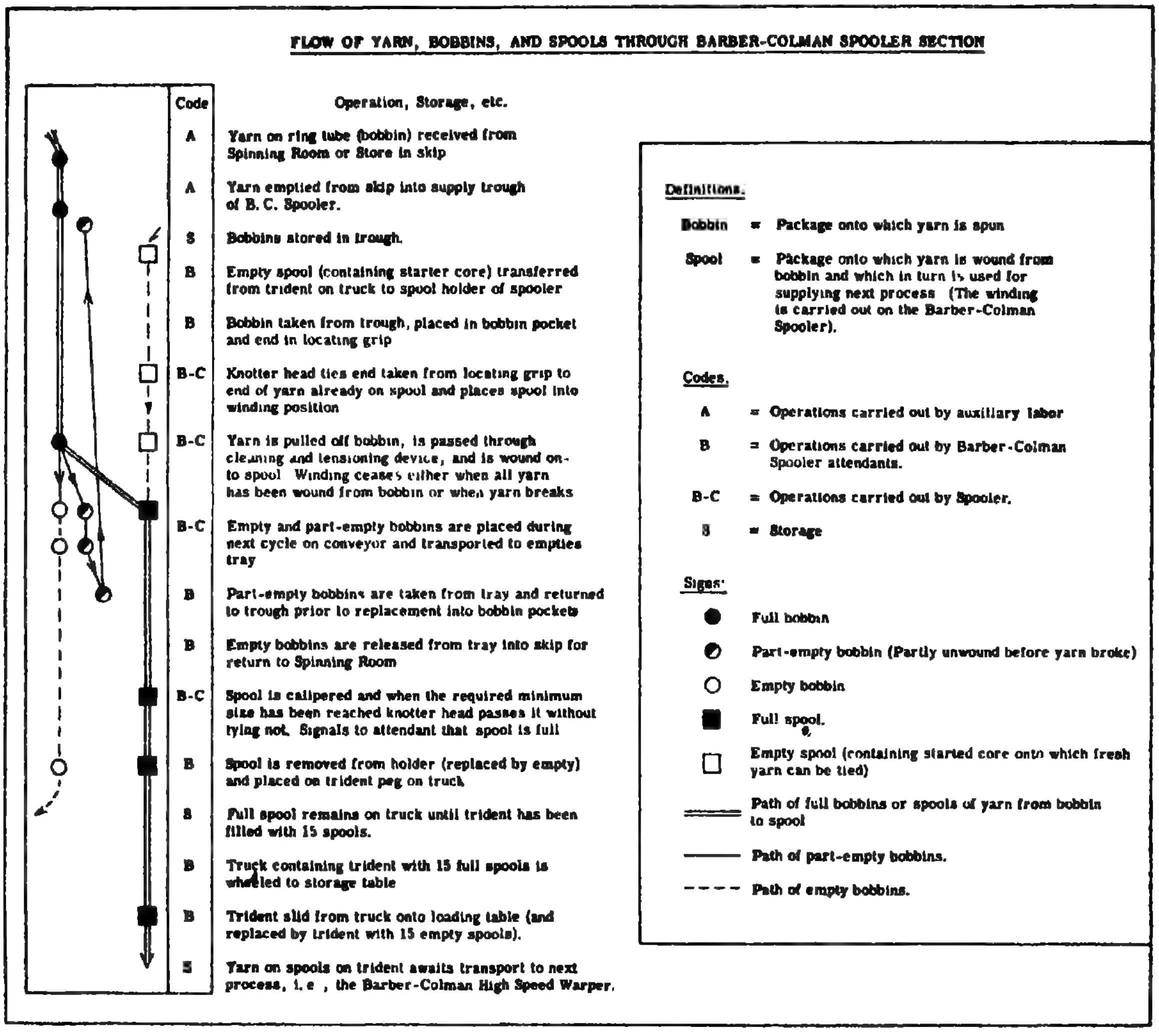


FIG. **15.14** FLOW OF YARN, BOBBINS, AND SPOOLS THROUGH BARBER-COLMAN SPOOLER SECTION.

8.7 EXAMINATION OF THE CONDITIONS UNDER WHICH CAPITAL ELEMENTS AND DIRECT LABOR ELEMENTS OF COST COULD BE SIMULTANEOUSLY ESTABLISHED AT OPTIMUM VALUES

This change makes the best of the original installation but falls far short of the ideal These machines are made in sizes varying between 90 and 306 winding stations in units of 18 stations. If the capacity/cost curve for this range is examined, it will be found that the cost per unit capacity is £89.6 per winding station for the 90-unit size and only £48.7 for the 306-unit size. This represents a reduction of 47.8 per cent in cost per unit of capacity. It will also be found by extrapolating the capacity/cost curve that the zero unit size cost would be £5,120, since the most complex part of the machine (i.e., the traveling knotter head) is as essential for one winding station as for 306. The 4-operator solution will, therefore, be cheaper than the 3-operator solution. In other words, the optimum is achieved at the nearest size to 306 winding stations, at which both operator and machine utilization can be maximized simultaneously. It followed that for winding 15s counts, the 216 spooler winding from a package weighing 0.30 lb. with 4 spooler operators per machine provided optimum conditions. The comparison be-

TABLE 15.6 COMPARISON OF POSSIBLE CHANGES IN OPERATION OF KNOTTER

Proposed change	Unit size	Spooler cost (£)	Cost per winding station	Optimum count	Optimum package weight (lb.)	Spooler operators per spooler	Annual spooler production (min. lb.)	Spooling cost d/lb. (1) Machine element	Spooling cost d/lb. (2) Direct labor element	Spooling cost d/lb. (3) (1) + (2)
Wound package only	126	9,200	73.1	16.75	0.165	3	2,275	0.0486	0.099	0.147
Wound package & building-up machine	216	12,050	55.8	14.50	0.303	4	4,495	0.0321	0.067	0.099

tween the results of the first improvement—i.e., to maximize the efficiency of the existing 126-unit equipment without changing it—and the maximum efficiency possible is shown in Table 15.6.

8.8 APPLICATION TO LOCAL CONDITIONS AND INTEGRATION WITH SPINNING UNIT

The maximum size of spinning package that is considered desirable in view of technical spinning requirements was 0.25 lb. The nearest practicable solution under these conditions, as indicated by Fig. 15.12, is to increase the spooler to the 198-unit size with 4 spooler attendants. This will give 100 per cent operator utilization and 100 per cent machine utilization on an average count of 16*s* and zero dwell.

8.9 CONCLUSIONS AND RECOMMENDATIONS

1. To install frames capable of producing packages of 0.25 lb. and to increase the existing spoolers from 126 to 198 units.

8.10 FOLLOW-UP

1. The scheme was submitted to the board for sanction of capital expenditure.
2. Sanction having been obtained, the detailed specifications of spinning and spooling equipment were drawn up and orders were placed.
3. The spinning equipment has been partially installed, the spooler equipment modified, and the staffing reorganized.
4. Target production on the whole spooler has not yet been obtained, but where the larger packages are in use, the individual spindle productivity is approaching the expected value.

9. AN ORIGINAL SYSTEM OF PRODUCTION CONTROL IN A STEELWORKS, STAFFORD BEER.

9.1 PERSON IN CHARGE OF O.R. WORK

Educated on classical lines, specializing in logic and metaphysical philosophy, with subsidiary studies in psychology. Trained in personnel selection in the Army, investigations in education and psychiatry; year and a half training course with the United Steel Companies Ltd., followed by appointment as personal assistant to the Commercial Manager at S. Fox & Co. Ltd., one of the branches of the United Steel Companies Ltd. Interest in the application of statistical methods to systems of control led to an analysis of the existing system at Fox's with recommendations toward the plan described below. Currently, Production Control Officer in charge of the general introduction and control of the system described, with direct responsibility to the General Works Manager.

9.2 SOURCE OF THE JOB

At the branch concerned (S. Fox & Co. Ltd.), special alloy, stainless and carbon steels are manufactured by the open-hearth, electric-arc, and electric high-frequency processes. A great variety of products is made from these various steels in addition to billets and bars—for example, sheets, strip, wire, and springs.

The problem was to improve the system of production control for this higher complexity. The objects were:

1. The most economic planning of output, securing the highest possible level of machine utilization consistent with the least possible deviation from the cheapest possible process routes. This would lead to—
2. Important knowledge of flow, which would give shorter and more accurate delivery promises and improved reputation among customers for reliability.

3. Increasing productivity, with reduced costs.

4. Greater general knowledge of the process, leading to better decisions by management.

These potential benefits were so great that the top management agreed on the installation of a pilot scheme to test the theory propounded. The manufacture of cold-rolled steel strip was chosen as typical of the extremely mixed production, over which detailed control was difficult to establish.

The General Manager placed the project, and the writer, under his personal supervision, for the duration of the experiment.

9.3 ANALYSIS OF THE PROBLEM

The stages of production involved in this study were: pickling (in which thick hot-rolled strip is cleaned in passing through a bath of acid), normalizing and annealing (in both of which metallurgical changes occur by heating in a continuous furnace), cold-rolling (in which the thickness of the strip is reduced on a number of different mills), grinding (where the strip is passed through a stationary machine), and slitting (where the wide thin strip is un-coiled through cutters, and recoiled onto a number of narrow drums). In each case, the limiting factor on output is the speed at which the machine can be run.

Cold-rolled strip is ordered by weight. By combining this weight with the width and thickness ordered, and by grouping narrow widths into optimum rolling widths (making due allowances for discard), the length in feet of any job may be calculated. Expressing this as a function of speed, a basic "running through" time measure may be obtained.

This basic measure is subject to a number of modifications: handling times, delays of various kinds, and so on. Further, more than one "pass" through a mill may be necessary to achieve the desired result. Even if all these factors can be accounted for, any list of component times may be incomplete, so that the constructed total time, which adds together known components, may not correspond with the actual time taken when the job is done. Unknown factors may enter into the equation.

If the ratio of constructed time to actual time is constant, it will be possible to make an accurate forecast of actual time by multiplying constructed time by the reciprocal of this constant ratio.

In addition to this forecasting function, the ratio is a measure of productivity, provided that all proper allowances of time have been made in computing the artificial time, since the difference between constructed and actual times is a measure of loss, which may be due either to technical factors or to factors of human inefficiency. Of these two types of loss, the technical factors (machines running at low speeds, breakdowns, and so on) are fairly easily measured. Hence a second constructed time may be computed to include them; its discrepancy from actual times will measure the element of human inefficiency.

Following suggestions made by the Anglo-American Council on Productivity, the better constructed time is called the "objective standard" (OST). The worse constructed time, which adds on the current technical losses, is called the "current standard" (CST). The recorded time from the shop floor is called the "current actual" (CAT). Thus a triple index of productivity is created, which is expressed in this way:

$$\frac{100OST}{CST} = \text{Current Technical Index } (CTI)$$

$$\frac{100CST}{CAT} = \text{Labor Utilization Index } (LUI)$$

$$\frac{CTI \times LUI}{100} = \frac{100OST}{CAT} = \text{Productivity Index } (PI)$$

Since this index is formed from differences, it is independent of the vicissitudes of time study. Ideal handling times have to be assessed for use in the *OST* and *CST*, but these are more readily decided than actual handling figures. Should they, even so, be inexact, and the index therefore inaccurate, the forecasts will still be correct, because the error committed in the analysis is repeated in the productivity index. When the forecast is made, the second error eliminates the first.

This was the basic theory behind the proposed scheme. Forecasts would be made by weighting the objective computation of time to be taken by an actual measure of inefficiency.

9.4 GROUNDWORK

Two problems had to be tackled.

First, by consulting with technical assistants and foremen in the shop, an insight into the processes had to be obtained and the objective and standard factors had to be agreed on. This was done, and a mathematical model of each process was constructed into which these objective and standard factors could be fed as variables.

Second, in order to obtain the actual figures needed to complete the productivity ratios, shop records had to be made available in convenient form. The manager agreed to certain modifications in recording to this end.

9.5 ANALYSIS OF INFORMATION

For any single job it was necessary to take the mathematical model, apply to it the agreed objective factors, and work out the objective time. Then the current standard time had to be found by applying the standard factors to the model. Finally, the actual output from the works had to be obtained, and the three results had to be combined to form a triple-index of productivity.

A program was devised to be carried out on a desk calculating machine. Every job done by the works department over a period of six months was analyzed in this way; the outcome was a vast library of triple-indices.

The information was first sorted by a punched-card analysis, and tabulated several times under different classifications. A statistical analysis was made to discover the significant causes of variation in productivity. When these causes had been isolated, it became possible to divide total production into separate groups, so that each group was homogeneous in terms of its level of productivity.

There were, in all, about 50 groups. Each one could be defined physically, in terms of a machine, a process, and a class of material. Each one could be defined statistically, in terms of a normal distribution of known mean and variance.

9.6 CONCLUSIONS

It would now be possible to make accurate forecasts of delivery. Having used schedules of objective figures to calculate an objective time for any job, this time could be adjusted in accordance with the particular job's productivity by using as a weight the mean value of the productivity group within which the job fell.

9.7 RECOMMENDATIONS

1. A system should be put into the department which would enable the planners to forecast production times on the principles described.

2. A visual control apparatus should be installed so that these forecasts could be combined to form a visible plan.

3. A routine sampling scheme should be set up to control (1) in accordance with whatever variations happened to occur.

The following arrangements were made to achieve these three objects.

9.7.1 The nomograph. The problem of the day-to-day calculation of fore-

casts was overcome by a multi-stage nomograph. This was designed and built specifically to calculate, from an order for strip, a forecast of production time required. The chart is six feet long and consists of 11 interlocking nomographic cycles. It is covered with 16th-inch transparent plastic, and transparent rules with sharply pointed ends are used to move across it; this, it is found, gives an accuracy of the order of 1 per cent error only. Constants are built in; the operator has merely to provide the information on the order form, and the value of variables contained in his schedules. The nomograph then solves the two equations for constructed time, and adjusts them by the appropriate productivity constant, the calculations of objective standard, the current standard, and the current actual time being forecast for a given job in something under a minute.

The nomograph is basically a system of logarithmic functions, which carry through the multiplications and divisions required by the mathematical model of the process. In this, it is largely orthodox, but the model does require that one of the five possible constants be *added* halfway through the calculation. This addition is achieved by a geometric device which may be new.

Suppose that a resultant, bearing its logarithmic scale has been reached in a calculation at point a. It is desired to move this point, on the same logarithmic scale, to a point $a + x$.

1. Construct a diagram as shown in Fig. 15.15. This is a projection of the logarithmic scale AB, through a fulcrum K, onto an arithmetical scale CD. In the simplest case, $AB = BK$, and $\theta = 45°$. θ can be calculated trigonometrically, however, for any ratio of BK/AB.

2. Next, draw vertical lines from several points on the arithmetical scale to cut the projected geometric progression lines, and join the intersections. For example, where 1 is to be added, the line EF is drawn; to add 2, draw the line GH and so on. Erase the construction lines, leaving only the fulcrum and the required number of parallel arithmetic scales, which need not be calibrated.

3. To move on the logarithmic scale from point a to a point $a + x$:

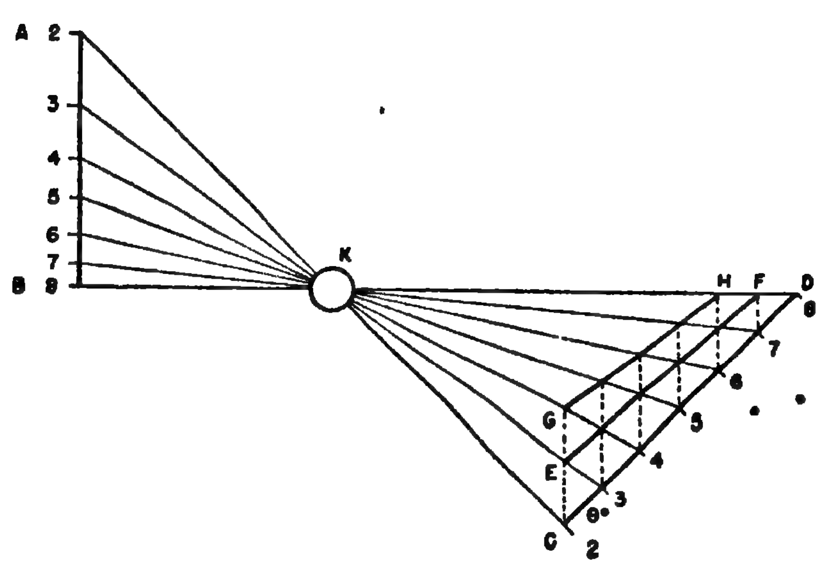
(a) Draw a line from a, through K, to intersect CD (at p).

(b) Use a vertical T-square to carry a line upwards to EF, GH, or other appropriate parallel, intersecting at q.

(c) Complete the triangulation, passing from q, through k, back to AB.

(d) The new point reached on the logarithmic scale is now $a + 1$ (from

FIG. **15.15** DIAGRAM ILLUSTRATING THE PRINCIPLE OF THE ADDITION SECTION OF THE NOMOGRAPH.



EF), $a + 2$ (from *GH*) or $a + x$ (from some other parallel).

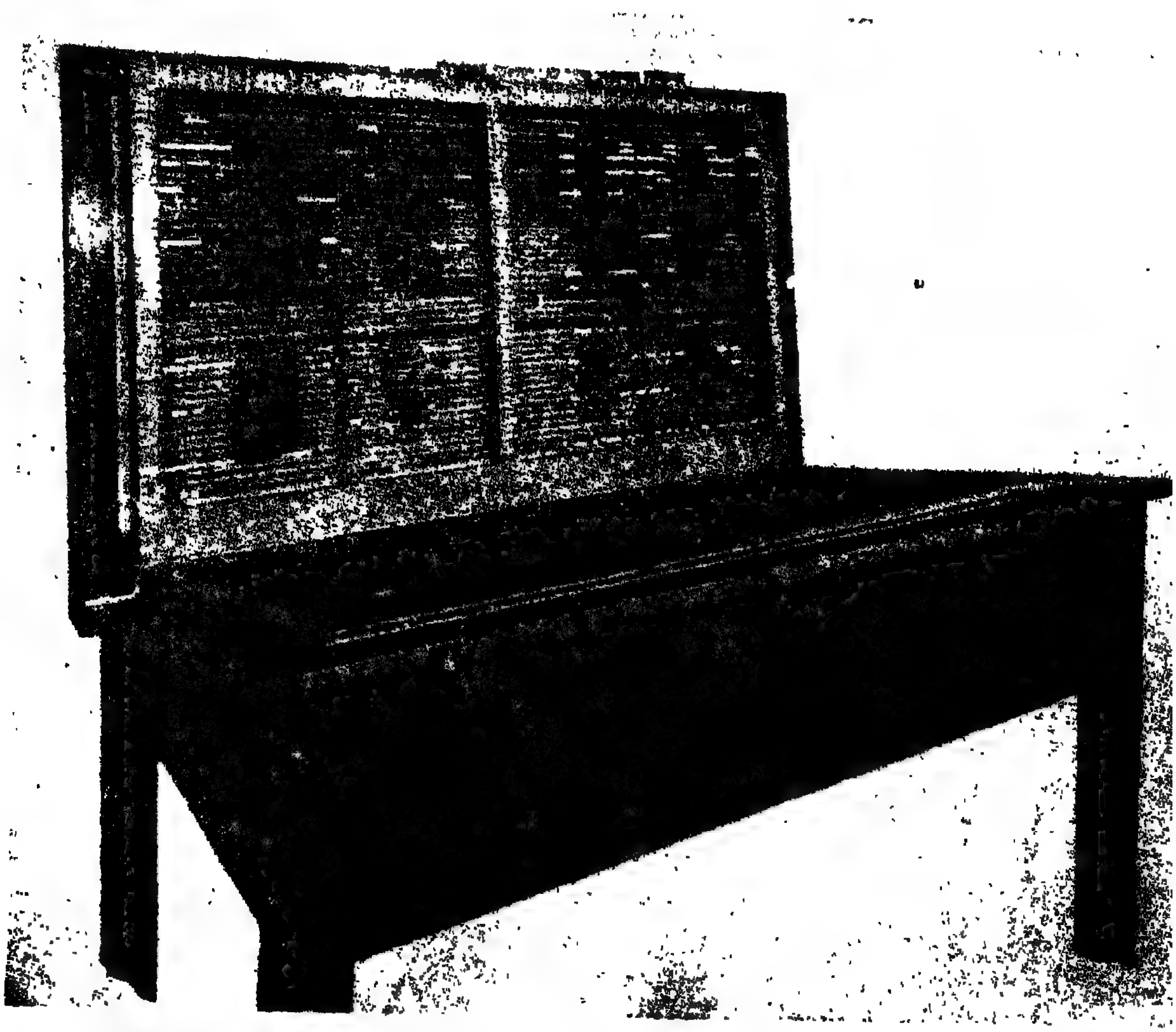
4. This situation is rigorous for any section of logarithmic scale covering the two intervals between three terms of a geometric progression. To extend the system, using the same fulcrum, continue the arithmetic scales in either direction, noting that the lines take on a new angle for each further pair of geometric intervals. The whole system of addition is based rigorously on the geometry of similar triangles, and correct angles for covering the whole irregular polygon of arithmetic scales are readily calculated by trigonometry.

9.7.2 Visual control apparatus. The difficulty in visual planning for a shop in which many orders pass through the same machines has been that, although neither a machine load or an order progress position can be shown against a time scale, it is virtually impossible to obtain a comprehensive view of both plans simultaneously.

The difficulty has been overcome very simply in the (provisionally patented) planning board illustrated in Fig. 15.16. This consists of a number of separate planning boards, set out in the same way, by machines and on a time base. A different class of product is planned on each board, and the boards are hinged together so that they can be viewed either individually or superimposed.

Hence the order progress of any one order can be examined by consulting the appropriate "class of product" board, where each order has its own characteristic colored symbols. The total machine load, on the other hand, is visible when all the boards are viewed together

FIG. 15.16 PLANNING BOARD.



and in superimposition. Machine time booked for an order appears in the third dimension against its correct machine, irrespective of the class of product to which it belongs.

9.7.3 Control charts. It remains to be noted that the productivity indices on which all conclusions depend are subject to change. It is necessary to watch each productivity group to see that its mean is not changing, and also that it is not bifurcating as the result of some latent factor. This is achieved by the use of quality control methods, applied to each group.

If the mean of a group changes significantly, a new group analysis is made statistically. The new mean triple indices must then replace the old ones on the final scales of the nomograph. The index bearing the arrows on those final scales is therefore adjustable to this end.

9.8 DISCUSSIONS AND REPORTS

The work which has been described took some time to complete. Throughout, discussions were held and reports were made on progress, while the scheme was installed piecemeal.

9.9 FOLLOW-UP

As a pilot scheme, the system installed was adjudged satisfactory. Some of the aims in the author's mind are long-term and have not yet been achieved, but the original objects are assured, and an increase in productivity has been effected. The productivity of the department in general was constant for a year prior to the scheme's introduction; after six months' operation, this figure had risen by 15.2 per cent. About a third of this rise is considered attributable to an incentive wage scheme, but this in turn was based in part upon nomographic forecasting. No other factor could be traced as influencing the improvement.

The scheme of production control described is therefore to be made permanent, and similar installations are to be made in the rest of the works. Meanwhile, the small department formed to carry through these schemes and to exercise their functional control has been fitted into the regular works organization.

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There is a large and growing number of books on the application of statistics in industry. The following is a short selection.

E. L. Grant, *Statistical Quality Control,* 2nd ed. (New York: McGraw-Hill Book Company, Inc., 1952).

O. L. Davies, *Statistical Methods in Research and Production* (Edinburgh: Oliver & Boyd Ltd., 1954).

A recent development, sometimes known as "linear programing," may become of considerable importance. A clear exposition of its basic principles is given in K. S. Lomas, *Allocation and Programming in Modern Economics* (Manchester, England: Manchester Statistical Society, 1951). Another important book is A. Charnes, W. W. Cooper, and A. Henderson, *An Introduction to Linear Programming* (New York: John Wiley and Sons, Inc., 1953).

The two societies devoted entirely to O.R. are The Operational Research Society (Great Britain), and the Operations Research Society of America. Both societies publish quarterly journals: *The Operational Research Quarterly,* 17 Park Lane, London, W. 1., England; *The Journal of the Operations Research Society of America,* 6410 Connecticut Ave., Chevy Chase, Maryland.

Societies interested in the statistical methods used in O.R. are The American Society for Quality Control, 70 East 45th St., Room 5036, New York 17, New York, and The Industrial Applications Section of the Royal Statistical Society, 4 Portugal Street, London, W. C 2, England.

Raymond Villers since World War II, has taught at Columbia University as Assistant Professor of Industrial Engineering, 1947-1952, and has been a lecturer at Columbia and at Stevens Institute of Technology. In 1954 he became Associate Professor of Industrial Engineering at Stevens. Dr. Villers has also lectured for the United States Army in 1949 and for the United States Navy in 1950-1951.

Dr. Villers is the author of *The Dynamics of Industrial Management* (1954) and of other scientific papers and, with the late Dr. Walter Rautenstrauch, of *The Economics of Industrial Management* (1949) and *Budgetary Control* (1950).

For many years Dr. Villers was a close associate of Dr. Rautenstrauch, one of the pioneers in the promotion of scientific methods in industrial management, and now heads the firm of Rautenstrauch and Villers, consultants in industrial management.

In 1946 Dr. Villers was awarded the DuPont de Nemours-General Motors Joint Fellowship of Research. He is a member of the New York Academy of Sciences, the American Association of University Professors, the American Society of Mechanical Engineers, the American Society for Engineering Education, the Newcomen Society of England, a Charter Member of the President's Council of the American Institute of Management, and a member of the Board of Trustees of Marlboro College. He is a member of the American Institute of Industrial Engineers and was elected vice-president for 1952; he is also an honorary member of Alpha Pi Mu.

Of French-American ancestry, Dr. Villers was born in France and was graduated from the Sorbonne, University of Paris. He has graduate degrees from several universities, including Columbia. During World War II, as a reserve officer in the French Forces, Dr. Villers served on the Personal Staff of the Admiral Commander-in-Chief of the Free French Navy. Later during the war he served with the United States Navy and became an American citizen.

SECTION 16

Industrial Budgeting

Raymond Villers

1. INTRODUCTION

In our modern civilization, almost anything can be sold. Within the obvious limits defined by common sense, any product has a market if it is offered at a price the prospective consumer can afford to pay.

At the same time, almost anything can be produced. Modern technical knowledge has reached the point where almost any desired product can be made, given the proper financial support for research and manufacturing.

Thus, it can be said that neither technical difficulties nor the lack of customers willing to buy are vital problems to modern industry. The most serious problem of modern industry, indeed the only real one, is a problem of *costs*. In everyday life, technical or personnel difficulties can generally be solved. The modern manufacturer's real concern is to produce at such a cost that his product can be sold at a price that a sufficient number of customers can afford to pay.

This qualification "a sufficient number of customers" is a fundamental one and requires some clarification. It should be

fully understood and recognized for what it really is—the key to economic success in manufacturing.

Mass production and the resulting low production costs have been made possible by extensive research in such fields as use of power, equipment, product design, and production methods. As a result, the costs of production have never been as low as they are today (after due adjustment for the inflated value of the dollar); but, at the same time, the structure of costs has undergone a fundamental change. The old blacksmith knew very well that he would be "out of the woods" if he could pay his helpers and his suppliers—if, in other words, he could sell at a price that would pay his *prime costs* (the cost of labor and the cost of material). For today's manufacturer, the situation is very different Although the cost structure varies with each industry and with each business, it is a common situation today in industry to find that the prime costs represent hardly half of the total cost. The other costs (power, depreciation of equipment, administration, research, marketing, and so on), generally known as *"overhead,"* account for the remaining expense.* Such overhead costs are characterized by the fact that most of them do not vary directly with production. Even if the plant should remain almost idle, staff salaries, part of the selling expense, advertising, indirect labor, maintenance, insurance, taxes, and many other overhead expenses would have to be paid and the burden of the depreciation charge would have to be carried. Such costs, which may vary (but not directly with production), are said to be *"constant."* The old blacksmith could practically ignore them. His shop's break-even point was about zero, which meant that, if his production was low, he would see his profits dwindle, but would run no risk of actually losing money.

Today's situation is quite different. Potential profits at a high volume of sales have been very much increased. Simultaneously, the break-even point of modern industrial enterprises has gone higher and higher during the last decades. The risk of losing money on each dollar of sales by having to operate below the break-even point has been as much increased as the chances of greater profit at a high level of production.

This is the strength and also the weakness of modern industry. In fact, such a development is not restricted to industry. It is also interesting to note that within the last 50 years or so, our life has paradoxically become easier and yet more difficult, simpler and yet more complex, safer and yet more fraught than ever with impending threat. The pilot of a modern jet plane travels as fast as sound. Unlike the old-time horseback rider, however, he cannot slow his pace at will, lest he fall and die. The span of his wings supports him only above a given minimum speed. Mass production also must be maintained above a given minimum rate, or else the enterprise goes out of business. Such a minimum rate depends upon production costs. This is what makes cost control so vital. It is not only a matter of making more or less profit. Cost control is often a matter of life or death for the enterprise.

This is why cost-control methods and procedures have gained wider and wider attention and have been projected into the future, whenever possible, in the form of budgeting.

Budgeting serves a dual purpose. Because it gives a reasonable estimate of what will happen if things are permitted to go on, it serves the purpose of enabling management to know in advance

* Cost data are among the best-kept secrets of industry. Some interesting figures were made available by the Federal Trade Commission after World War II when it released cost data collected during the war for the purpose of cost control. There are good reasons to believe that, although actual costs have changed since then, the relationships they show are still similar in character. (See *Wartime Costs and Profits for Manufacturing Corporations,* Washington, D. C.: Federal Trade Commission, 1947.)

what will be needed in terms of personnel, financing, material, and equipment, and what should be done, if at all possible, to avoid difficulties and improve the final result. It also serves the purpose of providing the yardstick by which actual performances can be compared and thus measured. As such, budgeting is the best tool of cost control ever devised. This is especially true for such costs as factory expense, general overhead, and, even to a greater extent, selling expense, for which cost control without budgeting can hardly be fully effective.

Thus, budgeting is another and more effective way of controlling cost. More precisely speaking, budgeting is preventive cost control, just as oiling, greasing, and good operating care of equipment is preventive maintenance; and it is just as profitable to an industrial enterprise as preventive maintenance is.

We shall consider cost control and budgets as a whole, for they are most effective when permitted to complete and support each other. *Cost control* is a prerequisite to budgeting, for without an accurate knowledge and command of costs, there is no possible budget; *budgeting* is the logical development of cost control, for without a budget procedure, the best cost control may well perform too late or too little and thus fail to be effective.

Since no two businesses are alike, the reader should not expect to find in this study any ready-made formula that he can apply. An attempt has been made simply to present guiding principles based on many years of practical experience in teaching, management responsibility, and industrial consulting practice. Examples will be drawn from actual cases; forms and reports in current use by manufacturers will be reproduced. They are intended to illustrate the principles involved and to enable the reader to gain a better understanding of the field rather than to serve as a pattern to be adhered to. It will remain the reader's task to apply these principles of cost control and budgeting to the actual problems he has to solve.

There are two cardinal principles of cost control and budgeting that should be kept in mind at all times. Written or not, they are in the background of each of the following pages on the subject. They are:

1. *Cost control must be self-controlled.* This principle means that to be effective, cost control must be reliable. Inaccuracies in control cannot always be avoided, but they must be quickly brought to light. This can best be accomplished by a "tie-in" of the cost-control data among themselves and by a "tie-in" with the basic document of cost control, the profit and loss statement, the accuracy of which is in turn guaranteed by auditing procedures. Thus cost control can be said to be self-controlled (see Art. 7.1).

2. *Cost control must reduce cost.* Time and time again, the question is asked: "How much does it cost to have an effective cost control?" The answer is an emphatic one: Not only does it not cost anything; it actually saves a considerable amount of money.

The savings result from the fact that management, through detailed cost control, knows what to do to reduce cost and can, step by step, week by week, check the progress made in cost reduction.

The additional cost due specifically to the operation of cost control can and must be a minor one. Throughout this study, an effort will be made to recommend only those procedures that ultimately result in a net saving.

This purpose is best served when an organization finds it possible to centralize its control (see Art. 6.2) Among other advantages, the centralization of control, which is the key to functional decentralization, makes it possible to use multi-purpose reports. The multi-purpose report reduces the cost of control. It is so designed that a great deal of information needed for various purposes (cost control, personnel control, production planning, payroll, etc.) is collected on the same form, thus avoiding duplication of work. This form is then analyzed in the *control department*

(see Art. 6.2), with or without the use of punched cards and accounting machines. The control department then issues as many reports as desired, all of which are merely extracts from the few multi-purpose forms mentioned above. In all fairness to the reader, it should be indicated that such a concept of centralized control, based on the creation of a *control department,* is not universally accepted in industry. For this reason, we shall also describe solutions that may be adopted without creating a control department. At the same time, centralization of control, associated with functional decentralization, does seem to provide the answer to the problem of organizing a modern industrial enterprise on bases that are both economical and satisfactory to the members of the organization. In fact, this concept has recently gained increased acceptance in small corporations as well as in large ones.*

2. THE MANAGERIAL APPROACH TO BUDGETING

2.1 PLANNING AND CONTROL

The modern plant is a heavy and complex machine Its inertia is great: production cannot stop at will or start on short notice and be economical, nor switch abruptly from one item to another, nor be suddenly accelerated or reduced without creating deep disturbances. It takes time to prepare the tools, jigs, fixtures, and conveyances for production, to issue the specifications and decide upon methods, to train new personnel, supply the materials, or design and produce new products. Yet these are only a few of the many problems to be solved by the modern manufacturer.

To have the time needed for all these activities, advance planning is necessary, weeks, months, or even years ahead.

Such planning is by necessity complex, because it involves the coordination of, and later serves as a basis for, the control of many different activities: engineering, financing, research, maintenance, training, building, personnel, administration, accounting, and so on. But its advantages have proved to be so great that the need for planning is hardly disputed today. The questions are rather: How detailed and how rigid should planning and control be?

The answer to these questions is highly controversial. Almost all shades of opinion can be found among the scientists who concentrate on the study of industrial production problems and among the executives who have to face such problems and solve them, for better or for worse, day after day.* In this section, although the various theories and practices in planning and control will be indicated when necessary, an attempt will be made to present, with details, a certain approach to the problem: the managerial approach to budgeting. This concept is best characterized by the answer it gives to the two fundamental questions previously raised.

2.2 HOW DETAILED SHOULD PLANNING AND CONTROL BE?

In the managerial approach, budgeting *is* managing; more precisely, it is managing in advance. Managing means giving to the right person instructions that are so detailed that whoever receives them should be able to understand what to do, when to do it, and how to do it, in order to accomplish what was intended. Furthermore, managing means control. It means that the one who issues the instructions must compare actual performance with these instructions and decide whether they have or have not been properly followed. In the managerial approach

* See for instance American Management Association *Reports to Top Management, 1953*

* For an interesting description of the various views held in industry, see "Proceedings of the Second Conference of the National Society for Business Budgeting," New York, 1952.

to budgeting, this is exactly what budgeting is; only, the instructions are given some time in advance—weeks, months, or years.

A budget is thus much more than an accounting document that shows anticipated income and probable expense. Of course, budgeting makes extensive use of accounting methods and techniques. Fundamentally, a budget, in this concept, is a plan for the management of an organization in the weeks, months, or years to come. Somehow, either expressly or implicitly, the budget must then take care of every aspect of management at a future time; it must provide a plan of action and a basis for control.

2.3 HOW RIGID SHOULD PLANNING AND CONTROL BE?

There is no sure way to predict what the economic situation will be next year: inflation or deflation? expansion or recession? How, then, can one plan the sales, production, expenses, and expansions of a business months or years ahead? If one attempts to do so, what provisions should be made to take care of unforeseeable circumstances? The challenge to planning is obvious. At the same time, it is vital to plan ahead if one wants to produce economically and therefore be in a competitive position.

How rigid should the plan be? If it is too rigid, the risk is that orders may have to be canceled and sales lost because the provisions were less than the actual requirements; or, on the contrary, that inventory may be dangerously inflated or the capacity of production over-extended because the forecasts were over-optimistic and were not adjusted soon enough to the actual conditions of the market.

On the other hand, if the plan is too flexible, it may still be an excellent instrument of control, because it still will provide a yardstick of comparison showing what the actual performance should have been in relation to the actual volume of activity. But it will be of limited help in managerial planning because it will not provide sufficiently detailed guidance.

The solution lies obviously in a compromise between the need for rigid planning if one wants to produce economically and the need for flexible planning if one wants to produce without taking excessive financial risks. The compromise is based on the idea that the budget should define a certain goal and the ways and means of reaching this goal (sales forecasts, inventory, production and expense budgets, capital expenditure program) within a certain period, and that periodical revisions of the budget during that period should either confirm the goal or modify it. But—and this is a very important concept—such revisions are not to be considered as defining new goals unrelated to the original one. Changes will be expressed in *plus* or *minus* from the original estimates and the whole planning of the organization will be thus *adjusted* rather than re-designed.

More details will be given concerning the methods to be followed. Experience shows that, after a few years of practice, an industrial organization is in a position to forecast its future activity, at least a year in advance, with such a degree of precision that, barring extraordinary circumstances (war, etc.), the adjustments to the budget will be of comparatively small magnitude and will generally create no serious problems of management. This is why the method is economical. As far as extraordinary circumstances are concerned, they are a blow to any industrial organization, with or without a budget; but experience shows that the practice of budgeting definitely gives management an increased ability to withstand their impact.

2.4 RELATIONSHIP WITH COST CONTROL

Budgeting is the logical consequence of, and simultaneously, in some respects, a prerequisite to, effective

cost control. The trend of cost control methods has been toward more and more estimating of future costs, culminating in the determination of standard costs. The last step of this evolution is budgeting, which is incorporating these estimates of costs into a broad plan of operation.

Moreover, some costs cannot be properly determined and controlled unless there is available a reliable estimate of total production. The budget provides such an estimate and is thus a prerequisite to cost control as well as to the logical development of cost-control methods.

2.5 ORGANIZATIONAL PROBLEMS

The role of the budgeter in the operation of budgets is an essential one; but the organization of his own department is a secondary, and, in any case, easily solved problem His attention should rather be focused on obtaining the cooperation of every member of the organization. The budget should be the common project of everyone concerned. The task of the budgeter is, first, to put the budget in the form of statements and reports—a relatively easy task; second, to follow up the actual operations and compare them with the budget—also a relatively easy task; finally—and this is a most difficult task —to make sure that, at all times, the budget is considered by everyone concerned neither as a loosely designed outline nor as a strait jacket imposed upon the organization, but as a guide that shows the best and safest way to successful performance.

2.6 HOW TO INTRODUCE BUDGETARY CONTROL

The prerequisite to managing in advance is an orderly management in the present. No attempt should be made to introduce budgeting in an organization before the essential principles of scientific management have been applied, such as clear definition of lines of authority and responsibility, cooperation of personnel, coordination of activities, and cost control.

Once management in the present has reached a sufficient degree of scientific precision, it can attempt to budget future activities. This can be done progressively by first budgeting a period of a few weeks hence, then expanding until the normal budgeting periods can be considered.

Although no absolute rule can be given, the following periods are generally adequate:

For capital expenditures budgeting: Five years, with yearly revision.

For sales forecasts: One year, with revisions every three months at least and more often if conditions appear to change.

For inventory and production budgets: In accordance with the sales forecast.

For expense budgets: One year, with revision every four weeks.

For cash budget: One year, with revision every four weeks.

It should be fully understood that the above periods represent averages recognized as satisfactory on the basis of experience in various industries. However, they are subject to change with special conditions in a given business (especially the seasonal businesses and the job-order shops) or with special circumstances that arise suddenly.

When introducing budgetary control in an organization, it is advisable, if this has not been done before, to number each week of the year from 1 to 52 and to group the weeks in four week periods, numbered from 1 to 13, rather than to observe the traditional division into twelve months.

This arrangement is of great practical usefulness. It will probably meet at first with some resistance, because of the change of habits involved, but will in the long run be adopted without difficulty and will certainly greatly facilitate

FIRST QUARTER							SECOND QUARTER							THIRD QUARTER							FOURTH QUARTER						
JANUARY							APRIL							JULY							OCTOBER						
WK	M	T	W	T	F	S	WK	M	T	W	T	F	S	WK	M	T	W	T	F	S	WK	M	T	W	T	F	S
1	1	2	3	4	5	6	**14**	2	3	4	5	6	7	**27**	2	3	4	5	6	7	**40**	1	2	3	4	5	6
2	8	9	10	11	12	13	**15**	9	10	11	12	13	14	**28**	9	10	11	12	13	14	**41**	8	9	10	11	12	13
3	15	16	17	18	19	20	**16**	16	17	18	19	20	21	**29**	16	17	18	19	20	21	**42**	15	16	17	18	19	20
4	22	23	24	25	26	27	**17**	23	24	25	26	27	28	**30**	23	24	25	26	27	28	**43**	22	23	24	25	26	27
5	29	30	31				**18**	30						**31**	30	31					**44**	29	30	31			

FEBRUARY							MAY							AUGUST							NOVEMBER						
WK	M	T	W	T	F	S	WK	M	T	W	T	F	S	WK	M	T	W	T	F	S	WK	M	T	W	T	F	S
5				1	2	3	**18**		1	2	3	4	5	**31**			1	2	3	4	**44**				1	2	3
6	5	6	7	8	9	10	**19**	7	8	9	10	11	12	**32**	6	7	8	9	10	11	**45**	5	6	7	8	9	10
7	12	13	14	15	16	17	**20**	14	15	16	17	18	19	**33**	13	14	15	16	17	18	**46**	12	13	14	15	16	17
8	19	20	21	22	23	24	**21**	21	22	23	24	25	26	**34**	20	21	22	23	24	25	**47**	19	20	21	22	23	24
9	26	27	28				**22**	28	29	30	31			**35**	27	28	29	30	31		**48**	26	27	28	29	30	

MARCH							JUNE							SEPTEMBER							DECEMBER						
WK	M	T	W	T	F	S	WK	M	T	W	T	F	S	WK	M	T	W	T	F	S	WK	M	T	W	T	F	S
9				1	2	3	**22**					1	2	**35**						1	**48**						1
10	5	6	7	8	9	10	**23**	4	5	6	7	8	9	**36**	3	4	5	6	7	8	**49**	3	4	5	6	7	8
11	12	13	14	15	16	17	**24**	11	12	13	14	15	16	**37**	10	11	12	13	14	15	**50**	10	11	12	13	14	15
12	19	20	21	22	23	24	**25**	18	19	20	21	22	23	**38**	17	18	19	20	21	22	**51**	17	18	19	20	21	22
13	26	27	28	29	30	31	**26**	25	26	27	28	29	30	**39**	24	25	26	27	28	29	**52**	24/31	25	26	27	28	29

FIG. **16.1** SCHEDULING CALENDAR.

the procedure of budgeting.* It eliminates the otherwise cumbersome designation of the weeks by their beginning date and ending date; it will also avoid the difficulties resulting from the discrepancies between the end of the weeks and the end of the months. In short, this comparatively minor change in established habits will go a long way toward avoiding irritating presentation and computation problems in the operation of a budget. A calendar presented as the one in Fig. 16.1 and distributed throughout the organization will be found useful. (In Fig. 16.1, the Sundays are omitted, since the five- or six-day week is a general rule.)

* For more details on how to introduce budgeting see Walter Rautenstrauch and Raymond Villers, *Budgetary Control* (New York: Funk & Wagnalls Company, 1950), Chapter XIV. See also Raymond Villers, *The Dynamics of Industrial Management* (New York: Funk & Wagnalls Company, 1954), Chapters 9, 15, 16.

3. BUDGETING THE PRODUCTION PROGRAM

3.1 THE SALES-INVENTORY-PRODUCTION RELATIONSHIP

Over the years, the inventory of United States manufacturing corporations has constantly been many times as big as their cash (two or three times as big, or even more). At the same time, inventory is a more dangerous asset than cash. It may rapidly become obsolete and almost valueless through no direct fault of its owners. Its safekeeping, even under favorable circumstances, is the origin of substantial expenses such as warehousing and insurance expense, and inventory always requires the investment of a substantial part of the working capital.

All these factors emphasize the expense, risk, and difficulty involved in keeping a large inventory. Yet, to maintain inventory at too low a level may also be expensive, risky, and the source of many difficulties.

In modern manufacturing, it is always expensive and, because of set-up costs, sometimes economically impossible to produce goods in small lots. It will often be advisable to produce a larger lot not only to fulfill orders presently on hand, but also in anticipation of future orders, if the product is to be sold at a price that can be paid by customers who place orders of average size (see Section 3, Art. 8).

Moreover, sales are sometimes lost if the producer is not able to deliver the goods at the time the customer needs them. The unavoidable delays in obtaining the raw material, and in producing, transporting, and delivering the goods provide another reason for maintaining inventory at a certain level.

Finally, maintaining an inventory of a given size helps to stabilize production. Ups and downs in sales are unavoidable. Ups and downs in production can be avoided by the skillful use of the inventory's reservoir. Unless such a use of inventory is carefully planned, however, it may lead to an excessive and very dangerous accumulation of goods. This is why effective stabilization of production must in most cases be associated with sales forecasting and budgetary control.

Stabilization of production is the source of many advantages. The numerous businesses that have introduced budgetary control and have obtained, as a result, a stabilization of production never reached before, have experienced remarkable reductions in costs and improvement in the general operation of the business.

According to its controller, Mr. Edmund S. LaRose, the Bausch and Lomb Optical Company, as a result of the introduction of budgetary control in the early 1920's, reduced the labor fluctuation, above and below the average monthly number of employees, from 33.5 per cent above average and 10 per cent below average number in 1924 to 4.3 per cent above and 4.2 per cent below in 1930. In the years after 1930, the pattern remained about the same, or rather became even more satisfactory from the point of view of stability of employment.*

More secure jobs attract a better working force and improve the morale generally; stabilization of employment reduces the expense of training new workers; raw material can be purchased more economically and delivery of finished goods can be arranged more effectively; and manufacturing lots can be of the most economical size.

In one manufacturing company that faces the problem of highly seasonal sales, the introduction of budgetary control and the resulting stabilization of production, as compared to the previous ups and downs in production and employment, originated a saving of more than 15 per cent in direct labor expense alone, together with substantial reductions in other items of expense.

For many years, the manufacturer of a given brand of refrigerators suffered greatly from seasonal variations. Production was increased in the spring to fill the seasonal summer demand, workers had to be trained at their jobs, additional supervision was needed, and overtime was expensive. The introduction of budgetary control based on sales forecasting changed the whole pattern of operations. Production was stabilized at an almost horizontal level throughout the year, with slight variations accounted for by vacations, inventory-taking, maintenance, and so forth. The graph in Fig. 16.2 illustrates this change (data are for the purpose of illustration only). On this graph, actual and budgeted sales followed the same trend that is marked "Sales." This will not always be the case. The methods to be followed to adjust production when actual sales depart from budgeted sales will be discussed later on (see Art. 4.7). Even so, production will not proceed by disorderly ups and downs, following the sales pattern more or less closely, instead, it will be adjusted to sales from

* Information provided by Mr. Edmund S. LaRose, one of the early pioneers in industrial budgeting, Controller and Member of the Board of Directors, Bausch and Lomb Optical Company.

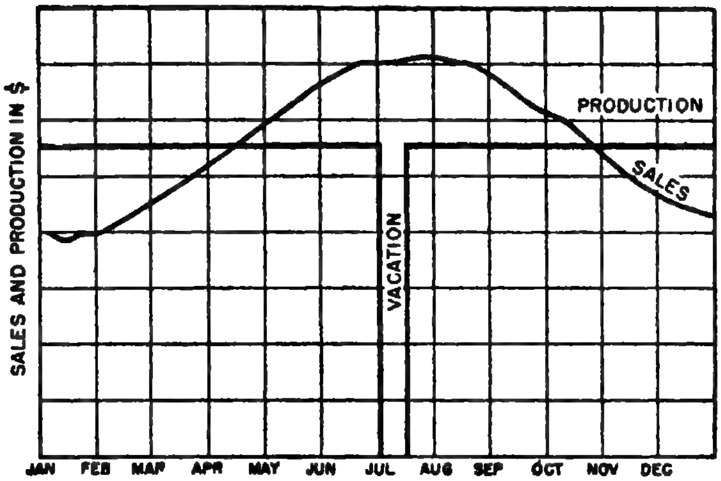


FIG. **16.2** GRAPH ILLUSTRATING PRODUCTION STABILIZATION.

time to time by scheduling the output at successive levels that remain constant over an appreciable period of time (weeks or months).

Ups and downs in production, which would be the logical consequence of seasonal or accidental variations in sales, are thus avoided by the use of inventory. Contractions and expansions of inventory act as a sort of flywheel to operations.

Stabilization of production at the same time emphasizes the need for inventory control, so as to keep within safe limits the size of the reservoir thus utilized to compensate for ups and downs in sales.

The above considerations reveal a fundamental conflict underlying the problem of inventory in industry. An inventory may be too large and yet it may be too small. In either case, expenses, difficulties, and risks are involved. To determine the optimum size of inventory in relation to future orders and to adjust and stabilize production accordingly are the keys to success in modern manufacturing.

Obviously, the optimum size is a compromise between the conflicting factors that have just been reviewed. How can the budgeter determine the desirable size of the inventory for each product or group of products?

Since an inventory fluctuates, the first step is to determine the lowest permissible limit of inventory for each product or group of products. The limit may be zero. This will be the case, for instance, for all the goods manufactured on special orders or for rapidly perishable goods.

As a rule, however, a going business needs to have on hand a certain quantity of most of the items it produces. A drug manufacturer, for instance, would lose his good-will if he were not in a position to deliver immediately such staple articles as penicillin, aspirin, or thousands of other items of current use.

The minimum safety limit is that amount of inventory below which it is considered that the inventory should at no time be permitted to go in order not to interfere with the delivery of orders. This safety level is determined for each product by the sales manager, who takes into account the habits of the customers, the usual size of single orders, the possibility of sudden orders, the degree of urgency with which a product may be needed, and similar factors. He will also, in cooperation with the production manager, take into account such factors as the minimum time required for production of a given item. Finally, he must also consider the time involved in transportation, warehousing, and delivery. If the demand for the product is highly seasonal, it may be

desirable to determine more than one minimum safety limit throughout the year.

In any case, it should be clearly understood that the minimum safety limit is *not* the level at which the inventory can normally be kept. The more the production is stabilized at its most economical level, and the more diversified the production, the greater the chances that the inventory will have to be maintained at a substantially higher level. In a plant that manufactures hundreds or thousands of different items, the production is generally scheduled so that the same item will not be run more than a few times a year. To maintain the inventory of such an item above its minimum safety limit at all times between two runs, it will be necessary to maintain an average inventory substantially higher than the minimum safety limit.

To eliminate the risk of losing sales and good-will by lack of inventory, an emergency procedure is generally provided. Production of a given item will be immediately ordered if the inventory happens to reach or fall below the safety limit. Such emergency orders, however, always have a disruptive effect on orderly production scheduling. Since they are the source of unnecessary expense (excessive set-up cost, overtime, waste of material, etc.), they should be avoided. The way to avoid them is to budget production at such a level that the inventory, while fluctuating between a maximum and a minimum, will at all times be above the minimum safety limit. At the same time, the inventory should be kept within reasonable upper limits to prevent an excessive and dangerous accumulation of goods. How can the proper upper limit be determined by the budgeter?

An approach to the problem is provided by the well-known financial ratio of sales to inventory (inventory turnover) used for the interpretation of financial statements. Such a ratio provides a yardstick for measuring the size of an inventory in relation to sales. It opens the way to the use of standards.

For example, during a given year, a business sold 1,200,000 units of product A. During the same period, 400,000 units of the product were, on the average, carried in inventory throughout the year. In such a case, the inventory turnover for product A was $1{,}200{,}000/400{,}000 = 3$.

The yearly inventory turnover is the ratio of annual sales to average annual inventory. It is also the number of times the inventory "turns over" during the year.

The larger the turnover, the smaller the amount of working capital necessary for a given volume of business, and, all other things being equal, the larger the percentage of operating profit on the capital invested. Less inventory for a given volume means less insurance, less loss from spoilage, obsolescence, or price decline, and less interest charges. This is why the inventory turnover is currently used as one of the measures of the efficiency of operation in a business. Due consideration being given to the conditions of operations and the kind of business, the greater the turnover the more efficient the management (see Art. 5.6).

Inventory turnover as a measure of management efficiency is generally computed as the ratio of total annual sales to the average of the total inventory carried throughout the year. As such, it can be used by the budgeter only in a few cases, because of the difficulty generally encountered in computing a meaningful "average inventory." If the range of variation from the average were not substantial, the average could be used directly, but such is rarely the case.

In fact, to avoid unduly complicated computations it has been found advisable to use periodically the actual instead of the annual average inventory turnover figures and to compare them once a year, or more frequently, against the predetermined standard turnover ratio. This procedure will now be explained.

For budgeting purposes, the ***standard inventory turnover*** is defined as the ***desired ratio of annual sales*** to ***actual***

inventory at a given time. This time will generally be the end of the fiscal year, although it may also, in seasonal businesses, be the end of a month or of a few significant months of the year. The time at which the actual ratio is computed should be so chosen that the ratio will be as meaningful as possible (for instance, beginning or end of the seasonal peak of the seasonal production run, etc.). To compute the ratio at this time is to measure the inventory on hand with the most appropriate yardstick—namely, the current yearly sales. By comparing the actual ratio to a predetermined standard ratio, it is possible to say whether inventory is excessive and should be reduced, or is insufficient and should be increased.

How to determine the standard is one of the problems the budgeter will have to solve in each individual case. The turnover of a product is a very important matter and the figure given to management as the one to aim for cannot be determined lightly.

As a matter of fact, the determination of the standard turnover of each product—which is required for proper budgeting—is one more instance where budgetary control will be of value to management as an additional aid for cost saving. It provides the opportunity for a systematic checking of the turnover, product by product. It will more than once throw light on unduly slow-moving lines of production, which otherwise would probably have remained undetected (see also Art. 5.6).

Actual turnovers—or, if possible, their average over a period of years—should certainly be taken into consideration when determining the standard to be used for budgeting. They should not, however, be accepted as such without further examination. An estimate should be made of production requirements, shipping facility, marketing conditions, and all the other factors that may influence the turnover. A comparison should be made among the various lines of products, and substantial differences in the turnover should be accounted for or corrected before standards are finally accepted. Periodical checking and revision of standards must be made.

Before leaving the subject of determining the standard turnover, we must point out a possible difficulty in defining the "inventory" and in choosing the proper unit with which to measure sales and inventory.

A product may be sold at various prices: wholesale, retail, export price, net or at a discount, FOB or delivered, and so on. Prices may even change during the year.

The valuation of inventory creates an obvious problem if no standard costs are used. Even with an accounting system based on standard cost, there is a question of comparing the goods in inventory (at cost) with the goods sold (at selling price).

The easy solution of using data expressed in physical units will sometimes be adequate and should then be preferred. The use of dollar figures is usually necessary to obtain a general picture of the situation when there are many lines of products. The dollar figures are the only ones in such a case that can be easily grouped and combined.

These difficulties must be solved when the turnover ratio for a particular business is computed. Depending on given conditions, one or another solution will be adopted. Among the most practical solutions are these two:

1. Either: Use the ratio *cost of sales* to *inventory* instead of the ratio *sales* to *inventory*, thus eliminating the impact of the multiple selling price.

2. Or: a. Determine an average (or standard) selling price for each item, to be kept throughout the year even if selling prices vary.

b. Express all sales in terms of standard selling price.

c. Value inventory at standard selling price.

The sales figure to use for computing the turnover ratio is always the net sales for one product (or for a group of products), but which components of the inventory figure to use (finished goods, work in process, raw materials)

will vary according to the kind of business being budgeted. If the raw material used for one product can easily be individualized, it might be a good policy to use the total inventory figure concerning the product (its raw material, goods in process, and finished-goods inventory). Sometimes there will be no choice. In the bakery industry, where fresh bread is baked every day, nothing would be gained by considering the ratio of sales to finished-goods inventory.

In most cases in the manufacturing industries, it is advisable to use only the aggregate figure of goods-in-process and finished goods as inventory and not to include the raw materials inventory. The reasons are:

1. The raw materials can rarely be identified as being used for the production of one product.

2. The accounting system will generally not provide a day-by-day figure for the finished goods as distinct from the goods in-process, but it will generally provide their aggregate total.

As a rule, therefore, the ratio of sales to inventory used for budgetary purposes will be understood to be the ratio of *annual net sales of the product* to *goods in-process and finished-goods inventory of the same product at a given time*.

It thus appears that the relationship *sales, inventory, production* is a fundamental one and that no attempt should be made to take a decision on a production budget before the sales budget and the inventory budget have been first determined. These two steps will now be considered.

3.2 THE SALES FORECAST

So many factors influence sales that experienced businessmen often deny the possibility of devising any practical method for forecasting sales either for short-term or long-term periods. This is not surprising, for two reasons. First, trade has always been a speculative venture; those who sell have always relied on current market conditions, judgments derived from experience, and on their skills in the arts of selling. Second, those who have been successful in practicing the art of salesmanship are usually not acquainted with the scientific method and hence are not in a position to understand that it can be of great assistance in the field of sales forecasting. The whole scientific management movement that arose at the beginning of this century was at first looked on with disfavor by the manufacturers of that day because it was considered an impractical substitute for the long-established methods of shop organization and management that had been "successfully" practiced for many years.

Yet it was the application of the scientific method to the control of the complex problems of production that made the country the great industrial nation it is today. Sales, of course, present a different problem from production, particularly since so many external factors influence the market and one's own position in that market. Sufficient experience with sales forecasting, however, is available to demonstrate that sales can be effectively budgeted within practical limits of accuracy in the most varied kinds of businesses.

Sales-budgeting procedures, however, will vary with each type of business and with each type of market supplied. The degree of accuracy attainable will depend on the extent to which the effect of all the factors that influence sales can be related to sales. For businesses that are long established and for which there is a well-recognized market, the problem of sales budgeting is concerned with answering the following questions:

1. What is the trend of company sales over the past two years?

2. How does this trend compare with the industry as a whole?

3. In what particulars has any company policy been responsible for its sales' having a better or worse trend than the industry as a whole?

4. What did the company do or fail to do that may account for the annual

ups and downs of sales from the general trend?

5. In what ways may the trend and variations in annual sales be related to the economic conditions of the markets —foreign, national, and regional—which the company serves?

6. In what terms (such as purchasing power, savings, investment market, credit, the inventories in the warehouses of merchants) may these economic conditions be meaningfully related to the trend and the annual variations in company sales?

These questions suggest that the general trend of a company's sales, and the annual variations from that trend, are due to two principal groups of conditions: (1) those within the company's power to control, that is, those related to company policy and action, and (2) those in the total economy and sector of the economy that affect all businesses and specific industries or markets.

A business does not navigate in quiet waters. Customers' changing needs and wants, the availability of competing products, competitors' activities, and similar factors that are *specific* to the market of a given product at any time have a determining influence. But the *general* influence is shown by the following example, chosen from among thousands of similar ones.

In 1928, the General Motors Corporation's sales were $1,400,000,000. In 1927, they were $1,200,000,000; and in 1929 they were $1,500,000,000. Such comparatively minor changes were mainly due to *specific* conditions: the needs and wants of the customers, the activities of the other manufacturers, and so forth. In 1930, and in subsequent years, the influence of the general economic conditions created by the depression were felt. Sales dropped to $900,000,000 in 1930, $800,000,000 in 1931, and $400,000,000 in 1932.

It appears, then, that the budgeting of next year's sales for a given company operating on a well-established market should be based on:

1. Conditions within the company over which it has specific control within the limits of the company's structure and operating characteristics.

2. Conditions in the market to which company operations must be adjusted or to which they must conform.

To acquire a clearer perspective of the conditions or factors influencing future sales, and particularly of the functional categories in which these factors may be grouped, it will be helpful to examine the problem of sales forecasting from the standpoint of company procedure in getting the information and data on which it should base its sales estimates. The essential elements of a rational procedure are as follows:

1. The company must rely on the salesmen who are in direct contact with its customers (ultimate consumers, dealers, or distributors) for data and information concerning:

   a. Consumer reaction to such matters as styles, models, prices, term payments, services, and other factors that may influence the consumer's desire or ability to possess the commodity offered.

   b. Dealer and distributor reaction to the advertising policy of the company, forms of distribution or dealer contacts, territory protection, price range of offerings, product design, packaging, sales services, displays, and the advantages and disadvantages of competitors' offerings from the marketing point of view.

2. The sales manager who is familiar with the character and markets of the industry of which the company is a part must be relied on for advice on trends in growth of the industry and on other matters specific to the commercial developments in the industry and the changing character of its markets.

3. The engineer must be depended on to supply information on ways and means to improve the product's design, to extend its range of commercial adaptability, to adjust it to desirable market-price ranges, to adjust its quality to market requirements, and to lower the cost of production. He is also in a

position to advise on new developments in competitive products and other technical matters that may influence the sale of the company's products.

4. The economist (either on the permanent staff or engaged as a consultant) has an essential contribution to make, for it is he who is capable of advising on:

a. The significant changes in general market conditions, both domestic and foreign.

b. The trends in the national and regional economies as affected by federal and state legislation, the national and regional incomes and their distribution, and the underlying currents in the total economy that will affect future sales.

5. Supplied with the information and data from all these sources, management must then determine major policies and formulate appropriate courses of action designed to improve the company's position in the market and to enhance its profits, or determine the best procedure on high policy to follow under the circumstances.

The above procedures indicate that market conditions have a continuous influence on company policy, and that company policy has a continuous influence on the company's position in the market. The sales budget, therefore, in the final analysis, results from an estimate of the interaction of all the factors involved.

Such factors can be grouped in three categories, namely:

1. The specific sales factor.
2. The general economic forces.
3. The administrative influence.

From a practical point of view, the above classification will be used as a basis for determining a sales budget in the following way:

First Step: Determine the year's sales item by item, and also by groups of items and for the business as a whole.

Since the budgeting procedures start by necessity before the beginning of any given year, the current year's sales will be known for only the first 9 or 10 months of the year. The probable results of the remaining months should be estimated by using, among other indications, the orders on hand at the time.

Second Step: Adjust the data to take into account any incident which, during the year, had either a favorable or an unfavorable influence on some aspect of operations and which had an exceptional and probably nonrepetitive character. For instance: a fire that resulted in a few weeks' or months' delay in shipments, a failure in the source of raw material, a strike in the plant that interrupted production, or a strike in a competitor's plant that stimulated sales.

Third Step: Adjust the data to take into account the specific sales factors that are expected to have either a favorable or an unfavorable influence on sales during the coming year. For instance: an improvement in design, the opening of a new market, the introduction of a competitor's new product, the growth of the market.

Fourth Step: The sales data thus adjusted can be considered as what the sales of next year would be if the general economic conditions remained unchanged. They should then be adjusted for the expected change in the general economic conditions.

Fifth Step: To counteract the influence of a change in the specific sales conditions or in the general economic conditions, management may decide to make high-policy decisions such as change in prices, advertising campaign, and improvement in sales service. An estimate should be made of the probable consequences of such administrative decisions with regard to sales.

Finally, the sales forecast is established by:

(1) Taking last year's sales as the basic data.

(2) Adjusting these data for the expected impact of change in the specific sales factors, the general economic conditions, and the administrative policy.

This sales forecast is then used for

the determination of the inventory budget, as will now be seen.*

3.3 THE INVENTORY BUDGET

Sales fluctuate throughout the year. If production is to be stabilized, inventory must also fluctuate to absorb the ups and downs of sales. The purpose of inventory budgeting is to control such inventory fluctuations between a safe minimum and a safe maximum.

The inventory budget for a given product (or group of products) should satisfy these three requirements:

1. Keep inventory constantly above the minimum safety limit (see Art. 3.1).
2. Keep inventory within the maximum determined for certain times of the year, by the sales forecast and the standard inventory turnover ratio (see Art. 3.1).
3. Stabilize production in accordance with management's directives (see Art. 3.1).

When the budget is being prepared in a going business, the budgeter never starts from zero. There is a given inventory on hand (actually known, or estimated if need be), which must be taken into account if requirement (2) above is to be satisfied by the inventory budget.

The sales forecast for the coming year should be compared with the actual inventory on hand. If the ratio is not approximately equal to the standard inventory turnover, an adjustment is required. This will be accomplished by budgeting an increase (or reduction) of inventory. *This budgeted increase (or reduction) will actually take place in the following months by producing more (or less) products than needed to meet the sales requirements as they are forecast by the monthly sales budget.*

Furthermore, the maximum size of inventory determined on the basis of the standard turnover should also be checked on the basis of the availability of working capital. If the budgeting of cash reveals that the inventory would absorb an excessive amount of cash in relation to the working capital available, either the inventory budget should be revised or additional sources of working capital should be found.

It thus appears that sales forecast, inventory budgeting, and production budgeting are three links of the same chain; none of the three can be considered without reference to the other two. Furthermore, all three must be considered in relation to the framework of operations defined by the financial structure of the business.

3.4 THE PRODUCTION BUDGET

The production budget, therefore, will be established only after the inventory increase or reduction has been decided upon. It will be established on the basis of:

1. The sales forecast for next year.
2. The actual (or estimated) inventory on hand at the end of the year.
3. The standard inventory turnover.
4. The availability of working capital.

The yearly production budget is not equal* to sales forecast, nor to sales forecast less inventory on hand, but to *sales forecast plus (or minus) the increase (or reduction) of inventory required to bring the actual inventory to the level of the budgeted inventory.*

At this point the budgeter has available a production budget for the coming year. If it is an accepted notion that production should be completely stabilized throughout the year, the production program is greatly simplified. Otherwise, the first step is to determine the few production levels to be reached during the year. Figure 16.2 illustrated the case where production is at one level of employment only. In very seasonal businesses, such a policy would often result in an excessive inventory at some time during the year.

* For a more detailed study of sales forecasting, see Rautenstrauch and Villers, *Budgetary Control*, Chapters I-V.

A pattern of production having two or more levels must then be established. As a result, the production pattern is determined week by week, for the whole year. But it is still expressed in dollars of sales.

The next step is to translate the figures into terms of direct labor hours, first for the plant as a whole, then for each division or department. These figures define the production budget, week by week, for the organization. They indicate a *level of activity,* without prejudging the production of any given items. The actual production will start only upon issuance by the proper authority of a *work order;* but in a budgeted business the total amount of direct labor hours required to complete the work orders issued during a given period should be about equal to the budgeted direct labor hours. Thus the production budget defines a framework of operation within which the authority who issues the work orders (production scheduler for instance) can operate

Furthermore, the production budget expressed in direct labor hours for each division or department will serve as a basis for the determination of the expense budget, as will now be seen.

4. THE EXPENSE BUDGET

4.1 GENERAL REMARKS

The *expense budget* is a forecast of probable expenditures directly related to current operations. It excludes capital expenditures, which will be the subject of another chapter It also excludes expenditures that are made in anticipation of future operations, such as those related to stockpiling of materials. It includes such book expenses as depreciation, for instance. The expense budget is thus distinct from the cash budget, which will be discussed later. For all practical purposes, the expense budget is a forecast of all expenses that are included in the profit and loss statement.

These expenses are traditionally classified in three broad categories, namely:

1. The manufacturing expense (also called cost of goods sold).
2. The selling expense.
3. The administrative expense.

The practical advantages of this traditional classification are well known. Among such advantages, one of the most significant is that of being universally accepted. Much inconvenience results from the lack of standardization in accounting. It seems proper not even to consider the possibility of abandoning one of the few principles that are accepted by all. At the same time, this classification, inherited from the past, does not by itself answer modern industry's need for control.

Perhaps the most vital problem of industry today is that of knowing the behavior of costs in relation to production When the production *rate* increases, some costs increase proportionally and somewhat automatically: these are the *variable costs.* Some do not increase proportionally or automatically, but by steps when the production rate reaches certain levels and when management makes certain decisions: in this section these are called *regulated costs.* Some do not increase with the rate of production: these are the *fixed costs.* For instance: the monthly direct material expense varies with the amount of monthly production—it is a variable expense; the monthly rent of the building is fixed; the total monthly salaries of supervisors, the number of which at any time depends on management's decision, is a regulated expense.

What is true of an increase in the rate of production is also true of a decrease. Variable costs will decrease automatically and proportionally to the reduction in production. The regulated costs are adjusted at intervals to declining production levels. The fixed costs cannot be reduced.

In the past, when the effective demand for a product was diminishing, the producer would reduce production and, by accepting a reduction in the margin of profits, could without excessive difficulty reduce his price at the same time. The

modern producer who tries to adjust his business to a decreasing effective demand faces the dilemma that, whenever he reduces his rate of production, the total cost per unit of production increases more rapidly because of the impact of costs that do not decrease with production.

His unit costs tend to increase precisely at the moment he faces the necessity of reducing his selling price. Hence the need for a more precise control of costs.

The traditional classification of expense data in manufacturing, selling, and administrative expense is extremely useful for the purpose of auditing. It tells very significantly what has happened and where it did happen during a given period while a certain quantity of goods was produced. It does not, however, give sufficient indication of what would have happened if the quantity of goods produced had been different. The variable, regulated, and fixed costs are not identified.

For budgeting purposes, this is precisely what should be done.

The secret of accurate expense budgeting is the ability to adjust past data to changes that are forecast.

The first step is to forecast the change —for instance, to forecast the future sales, the future wages, the future cost of raw material, and so on.

The second step is to determine how such changes will influence the expense of the business, which implies a knowledge of the break-down in variable, regulated, and fixed expenses. Past data will serve as a guide only insofar as the probable influence of the change can be determined. It is one thing to know that the foreman's salary will increase by 10 per cent and another thing to know the influence of such an increase on the total unit cost of each refrigerator to be produced next year at a rate of production greater by 7.5 per cent than last year's rate of production.

In other words, budgeting requires a break-down of expense that will show the *functional* behavior of the expense in relation to production.

While keeping the traditional frame of expense classification, it is therefore in order to consider each expense in terms of its functional relationship to production.

4.2 VARIABLE AND FIXED BUDGETS

There is no difference of opinion among budgeters on the need for determining the functional behavior of expenses in relation to production; but there are substantial differences of opinion on how to use such a relationship when budgeting the expenses.

Some authors and some executives advocate the use of *variable budgets.* In such a concept, future expenses are budgeted in relation to anticipated levels of production—two or three levels or more, or even a probable range of variation between a probable maximum and a probable minimum. The emphasis is on the need for accurate prediction of the relationship of expense to production, rather than on the need for accurate prediction of the expense itself. This approach is obviously a simple one, since it does not require precise sales, inventory, and production budgets based on reliable sales forecasts. Such sales forecasts are certainly difficult to establish within a few per cent of accuracy, especially in a time of economic uncertainty. Any method that enables the budgeter to dispense, even partly, with sales forecasting has an obvious appeal. In fact, the variable budgets are advocated by some noted authors and successful executives and should be regarded as an acceptable and interesting method.

The advantages of variable budgeting were pointed out as follows by the Budgeter of Allis-Chalmers Manufacturing Company, Mr. Walter R. Bunge:

> We establish actual budgets at three levels of volume—the anticipated level, levels far above and far below. . . . This type of budget has a distinct advantage in a time of economic uncertainty, particularly at a time of decline. Ordinarily there is a strong inertia in operating

costs, and statements tend to show higher costs for quite some period before action is taken to bring them into line. With this system of budgeting, however, every man who spends the company's money has already planned what he would need in case such a decline occurred, and he is ready.*

At the same time, variable budgeting has been strongly criticized by many experienced executives, controllers, and budgeters as being essentially a device of cost control rather than a true budget. This is, in the author's opinion, a well-founded criticism. One of the greatest rewards of effective budgeting is production planning and the resulting stabilization of employment, reduction in labor cost, easier material supply, tools supply, and so forth. Such rewards are only partially available, if at all, to the company using variable budgets.

Another solution is the *fixed budget*, based on the concept that sales can be anticipated within close limits of approximation (a few per cent), and thus that the inventory, the production, and the expense can be budgeted within comparable limits.

The validity of the concept of fixed budgeting has been amply demonstrated, over a long period of years, by many companies, and especially by one of the pioneers in the field, Mr. Edmund S. LaRose, Controller and Member of the Board of Directors of the Bausch and Lomb Optical Company. Selling a great variety of products, this company has been able, during the last 30 years or so, to apply very successfully the concept of fixed budgeting. Table 16.1 shows its 1951 budget (as established by the end of 1950) and the actual figures for the same year. Note that the actual figures are within 3 per cent or less of the budgeted ones. Note also that at Bausch and Lomb the sales forecast is made for the whole year and is considered as final some time in November of the preceding year. In 1951, the forecast presented an additional difficulty. As shown in the table, the 1951 budget was based on a forecasted increase in sales from 37.3 millions (actual sales 1950) to 49.8 millions (budgeted sales 1951). Such a substantial change obviously complicates the task of the budgeter. Even so, the table shows that the budgeter proved able to forecast sales *within 3 per cent* As a result, the expense remained also within a few per cent of the budget. In fact, the profit was slightly greater than expected, even though the sales did not

* "Second Conference of the National Society for Business Budgeting," New York, 1952.

TABLE 16.1 CONSOLIDATED PROFIT AND LOSS VERSUS BUDGET AND PRIOR YEAR BAUSCH AND LOMB OPTICAL COMPANY*

(in millions of dollars)

	Actual 1950	*Budget* 1951	*Actual* 1951
Income			
Sales, less returns, allowances and discounts	37.3	49.8	48.5
Other income, net	2	.2	.2
	37.5	50.0	48.7
Costs and Expenses			
Cost of goods sold	21.0	29.6	27.7
Depreciation of properties	.8	1.0	1.0
Selling, branch prescription service, administrative and general expenses	13.9	16.0	16.4
Interest expense	.4	.5	.5
Profit before Federal taxes and minority interest	1.4	2.9	3.0

* Reproduced by courtesy of the Bausch and Lomb Optical Company.

quite reach the anticipated volume. Such results are probably the best argument that can be given in favor of fixed budgeting.*

Other large organizations, such as General Motors, and many middle-sized companies are also known to have obtained spectacular results in sales, production, and expense budgeting.

One question will certainly arise at this point: Can it be done in any business? The following conclusions seem to be justified:

1. With the possible exception of the fashion industry and some other organizations such as job-order shops, the methods of fixed budgeting seem to answer adequately the needs of the manufacturing industry as a whole.

2. The forecasting of sales one year in advance within close limits of accuracy is possible only in businesses that have acquired long experience in forecasting and that have available detailed and accurate company records (sales, orders, inventory, and production records) for a long period of years.

3. When such conditions are not present, the principles of fixed budgeting can nevertheless be applied, without losing the essential benefits of the method, by shortening the forecast period and by following a flexible policy of periodical revisions. Such procedures of flexible budgeting will now be described.

4.3 DIRECT LABOR BUDGET

To budget direct labor is to evaluate the amount of direct labor that will be required for the fulfillment of the production program, which, as was shown in the previous article, was prepared in relation to the sales forecast, the inventory on hand, and the standard inventory turnover.

The production budget is expressed in terms of physical units or of dollars (standard or actual production costs). To budget direct labor is therefore to translate the production budget in terms of direct-labor units of measurement.

There are two ways of measuring direct labor, either by using the dollars of wages paid to the worker or the number of hours required to do the job. Depending on conditions of operations, accounting procedures, and management preference, either one or both may be adopted. The direct-labor dollar and the direct-labor hour are both being used currently in budgeting.

Since the cost of direct labor per unit of production is generally well known in industry, as a rule there will not be any serious difficulty in establishing the direct-labor dollar budget on the basis of the production budget.

The direct-labor dollar budget should be established not only for the plant as a whole but also department by department.

This break-down is helpful for measuring production in each department, as will be seen later in this article. It is also required for good management purposes; the direct-labor budget handed to each department at the beginning of the period will be the basis of its employment policy As was seen in the preceding article, the production program is established at various levels, which remain constant over a substantial period of time. The direct-labor expense budget, which directly reflects the production budget, is also constant over substantial periods of times. So also is the employment policy (hiring and laying off) followed by the various departments; this is one of the greatest rewards and most profitable results of budgetary control.

The direct-labor expense per unit of production is sometimes known only empirically on the basis of past experience or rough estimates, in the case of new products. More and more, however, this expense can be estimated with accuracy by the use of standards determined by time-and-motion engineers, with or without participation of representatives

* For a detailed study of the budgeting procedure at Bausch and Lomb Optical Company, where the concept was introduced in the early 1920's, see Rautenstrauch and Villers, *Budgetary Control*, Appendix C.

of the workers. These standards are standards of quantity of production based on standard wage rates.

Whether such standards are used or not, there will be some difference between budgeted and actual direct-labor expense. It is important to remember that the difference may be the total result of two distinct causes, namely:

1. A difference between the actual performance of the worker on the job and the performance that was expected from him by the budgeter.
2. A change in the wage rates.

It is a good policy to design the accounting system in such a way that the variance between actual and budgeted direct labor will be reflected by two distinct variance accounts, one for the variance due to the actual performance on the job, one for the variance due to a change in wage rates. This procedure will clearly show the facts as they are, and will open the way for appropriate managerial decision.

Such an accounting procedure is facilitated by the use of standard cost accounting. The businesses that do not operate on standard costs can open such variance accounts, however, for statistical purposes only, without fundamentally changing their accounting methods.

For budgeting purposes, it is obviously necessary to estimate the direct-labor expense in terms of dollars. It will sometimes be advisable also to compute the direct-labor budget in terms of hours of work. This computation will be greatly facilitated if the standards previously mentioned are available.

The reasons for budgeting the direct-labor hours are both technical and psychological.

Many cost-accounting systems are based on the allocation of overhead cost on the basis of direct-labor hours. Also, the "hour of work" is a tangible unit of measurement that appeals to supervisors. The budget may appeal more strongly to them and therefore be more likely to be taken into consideration if it is marked in the terms and units they best understand. This is especially true for low-ranking supervisory personnel. Such psychological factors should be given the greatest consideration by the budgeter. An expense budget that is not fully understood and respected by the production personnel is without value.

4.4 DIRECT-MATERIAL BUDGET

The direct-material expense is the cost of the material which, during a given period, enters into and becomes part of the product. This expense is to be distinguished from the cost of materials that are bought in anticipation of future production and also from the cost of materials that are consumed or used during the manufacturing operations, such as oils, waste, taps and dies, coal, water, and gas. (These are indirect materials, which are part of factory expense (see Art. 4 5).

It is important to define what constitutes the items of the direct-material cost before attempting to budget the expense. In fact, the valuation of the direct material is one of the delicate matters of cost accounting.

The cost of materials consists of the purchase price, plus freight and trucking charges incurred in conveying them from the place of purchase to the storeroom in the factory. This is the real cost of the material. However, it is not always convenient to apply freight and handling charges to specific materials, particularly when freight, express, and trucking bills include miscellaneous materials delivered Accordingly, materials cost, for practical purposes, is often taken as the purchase price, and the handling charges are listed as items of the factory expense. Sometimes such charges will be added in the form of standard burdens.

To budget the direct-material expense, it is necessary to take into consideration the methods of accounting actually followed in the business being budgeted. The rule is that the budgeter should attempt to estimate the direct-material expense that will be actually debited to the account "materials-in-process" at the time the goods are being processed.

In practice, when many raw materials are handled, when many purchases are made during the year, and when substantial variations of price exist, it will be necessary to use standard costs of direct material. In such a case, the same standard is used both for cost-accounting and budgeting purposes. Differences between the standard and actual cost of material are absorbed in variance accounts, according to the usual methods of accounting. The variance itself should also be budgeted if it is expected to be of a substantial amount. This is especially true for the price variance account when prices are expected to vary substantially.

Thus, it can be said that the budgeter should endeavor to forecast the actual amount that the account "direct-material expense" will show at the end of the year, in accordance with the methods of accounting actually followed by the business, and that his forecast should be based on the production program previously determined.

The production program is expressed either in dollars or in physical units of production (or in both terms). Budgeting direct material is translating the production budget into terms of the appropriate measurement units (physical units, standard cost, or actual cost) on the basis of a specific method of valuation (LIFO, FIFO, average cost), with or without adding an actual or standard transportation burden.

In most industries, the quantity of raw material needed per unit of production is determined with great accuracy. The budgeting of the quantity of raw material needed for the fulfillment of the production budget will not, in general, present any serious difficulty. The evaluation of the expense in relation to the quantity may require some computation by the accounting and the purchasing department, but will not present any fundamental difficulty. Therefore, the budgeting of the direct-material expense, based on the production budget, is usually a comparatively easy task.

It should be clear that the budgeting of the direct-material expense as just described is distinct from the purchasing program of raw material, which, because of its close relationship with cash problems, will be considered with the cash budget.

4.5 FACTORY OVERHEAD BUDGET

The two classes of manufacturing expense (direct labor and direct materials) that were considered above usually vary directly with the rate of production, particularly so in the mechanical manufacturing industries. In the process industries, direct labor tends to be constant over very wide ranges of production, because of the nature of the operations in such industries. The third class of manufacturing expense that we are now to consider—namely, the factory overhead—is more complex in character. It includes some items that are variable, some that are fixed, and some that are regulated or adjusted to higher or lower levels for higher or lower *ranges* of production.

The factory overhead is made up of a number of expense items. In a middle-sized business, it is not unusual to find as many as 100 separate account numbers under this heading These should be budgeted by departments, by the character of their relation to the rate of production (fixed, variable, regulated), and by such other classifications as may be useful for control purposes in particular types of industries. Classification by items may be desirable Classification by both productive and service departments is necessary for the assignment of responsibility for control Classification by character of variation with production is necessary for purposes of control of the economic characteristics of the business, particularly the gross profit and the break-even point, since these groups are *functionally* related to the rate of production and to managerial policy. The prime variable (production) against which these items and groups of expenses must be measured will be either the physical units of production, or the

standard direct-labor hours incurred in production, or the actual direct-labor dollars of sales or cost of sales, whichever is most applicable according to the nature of the products made, and the system of cost accounting used. These expenses will also be influenced from time to time by changes in prices for materials and services. Accordingly, any budget of factory expense established to measure the variation of such expense in total or in detail, with the rate of output, must be understood to be based on specific unit prices for materials and labor.

The factory overhead budget is preferably set up in cooperation with the heads of the several productive and service departments. Their participation in preparing the budget results in getting "grassroots" data on each department and establishes confidence and respect for the budget when it is issued. The department heads should be requested to give their estimates for those expenses for which they are responsible, which are usually the amount of indirect labor and the quantity of indirect materials. Experience has demonstrated that in a majority of cases the budgeter's office, being more statistically minded, is in a good position to suggest the probable expense for each department for a specified rate of production.

The final proposals will result from the cooperation between the budgeter and the department heads.

In adjusting to future levels of production data based on past experience, the use of graphical trend of expense-production relationship will be found useful. Such trends can be established for each department or for only some of the important production departments.

4.6 SELLING AND ADMINISTRATIVE EXPENSE BUDGET

These expenses are in the main composed of accounts that are regulated by executive decision. They also contain many items of fixed expense that are independent of the rate of production. The budgeting of these expenses, therefore, assumes a different character from that of manufacturing expenses.

Selling expenses are all those expenses incurred in creating a desire in the public to possess, in providing convenient places for procurement by the consumer, in transporting the products to the places of procurement, and in collecting the money. The function of this division of operations of a business is to find the customers, deliver the products to them, and get the money. Creating the desire to possess the company's products is accomplished through advertising, personal solicitation, and goodwill. Providing convenient places for procurement is brought about by the use of the company's own sales outlets or by contracting with others for the use of their outlets. Transporting the products from the factory to the places of procurement is done by rail, plane, truck, water-borne carriers, mail, and by other means.

All these activities concerned with connecting with the consumer are of a wholly different character from those concerned with the processes of production, which have just been considered. Accordingly, the establishment and control of the expenses associated with such activities are based on wholly different considerations. Yet upon examining these expenses, it is found that they fall into two principal categories: (1) those which are constant in time as established by administrative policy, such as the annual appropriation for advertising, and (2) those which vary directly with the quantity of output sold, such as commission on sales. Once the general framework of sales policy has been established, some of the constant expenses take the character of fixed expenses, such as the rent and other costs of maintaining sales offices. It is also characteristic of this class of business expense that there exists here the widest latitude for the exercise of administrative judgment and the greatest need for sound judgment both in determining the main framework of policy and in adjusting and regulating expenses-to-sales trends.

Another important characteristic of this class of activity is that its expenses must be controlled within the boundaries of gross profit margins. Furthermore, although the expenses of manufacture may be rationally related to the rate of production, many of the expenses of sales and distribution, such as advertising, do not relate themselves specifically to the rate of sales. They are related in only a general way. Accordingly, all these circumstances set the problem of the budgetary control of such expenses in somewhat different terms from those which apply to the budgeting of manufacturing expenses.

How, then, may these expenses be budgeted?

An analysis of a company's records of expense for selling and distribution will reveal that certain items will vary directly with shipments made. Among the accounts of this character are:

1. Freight and express.
2. Packing materials and supplies.
3. Commission on sales.

If the total sales of last year are divided into each of these items, the expense per dollar of sales of each is obtained. At this time, a study should be made of each of these expenses, with a view to reducing them while maintaining the same quality of service.

The net effect of such a procedure will be that reliable data are provided for budgeting the variable items of the total selling and distribution budget. At this time, a graphic portrayal of expense in relation to sales for the business as a whole will be found helpful.

The constant portion of the expense of sales and distribution must now be considered with reference to the operating profit aimed at. Among the items that come under review are those frequently classified as follows:

1. Salaries.
2. Rent, heat, light, and depreciation.
3. Traveling.
4. Sales promotion.
5. Telephone and telegraph.

These expenses are constant by administrative apportionment and can be regulated above certain minimums, which are usually referred to as the irreducible minimums. This review should begin with a statement of the amounts of each of these items for last year. If the traveling expenses, for example, are analyzed on a mileage basis, and if the daily cost for hotel accommodations is determined, it may be found that they are excessive and should be reduced and put under budgetary control. Every item of expense should be reviewed by the budgeting officer in cooperation with the sales manager, and definite schedules for each should be prepared for administrative consideration. The advertising and sales-promotion budgets, as a rule, are the ones wherein administrative policy and decision are most important. If the sales budget should be reduced, what will be the effect on sales if the advertising appropriation is cut, say, 15 per cent? Conversely, what increase in sales may be anticipated if this activity is stimulated by an increase of 20 per cent in appropriation?

The whole program of sales distribution may come under review, and the question of sales expense by territories in relation to the sales in those territories may receive serious consideration. In order that discussions on such matters can be based on reliable data, the budgeting officer should have compilations of expenses by territories, districts, or other appropriate geographic divisions. In fact, the sales and distribution expense budgets should be built up from the data on local points of distribution.

Finally, the administrative expense budget should be prepared. Administrative expenses are all those expenses other than manufacturing, selling, and distribution, incurred in operating the business. They are, as a rule, constant expenses. When administrative officers are paid bonuses on the basis of profits, that expense is variable.

In preparing the schedule of such expenses, the budgeting officer must be guided by an estimate of what each item of last year's expenses would have been at current prices for supplies, current rents, and current charges for other items.

This estimate must be adjusted for all anticipated increases and decreases. A final schedule of administrative expenses, together with the anticipated break-even chart of the business, showing the trend lines of manufacturing, selling, and administrative expenses, should then be reviewed, and a schedule of adjustments in such expenses, such as business increases or decreases, should be formulated. The effects of such adjustments, when reflected in the break-even chart, will show the consequences in profits.

4.7 PROCEDURE. CONTROL AND ADJUSTMENTS. AN ACTUAL CASE

Each organization has its own problems, its own habits, its own structure. It would not be desirable to attempt to introduce in a given company any rigid procedure just because such a procedure may have been successful in another business. The following is a description of methods that have been successfully applied in a manufacturing business It may provide helpful guidance to the reader who has to design budgetary procedures in a given company.

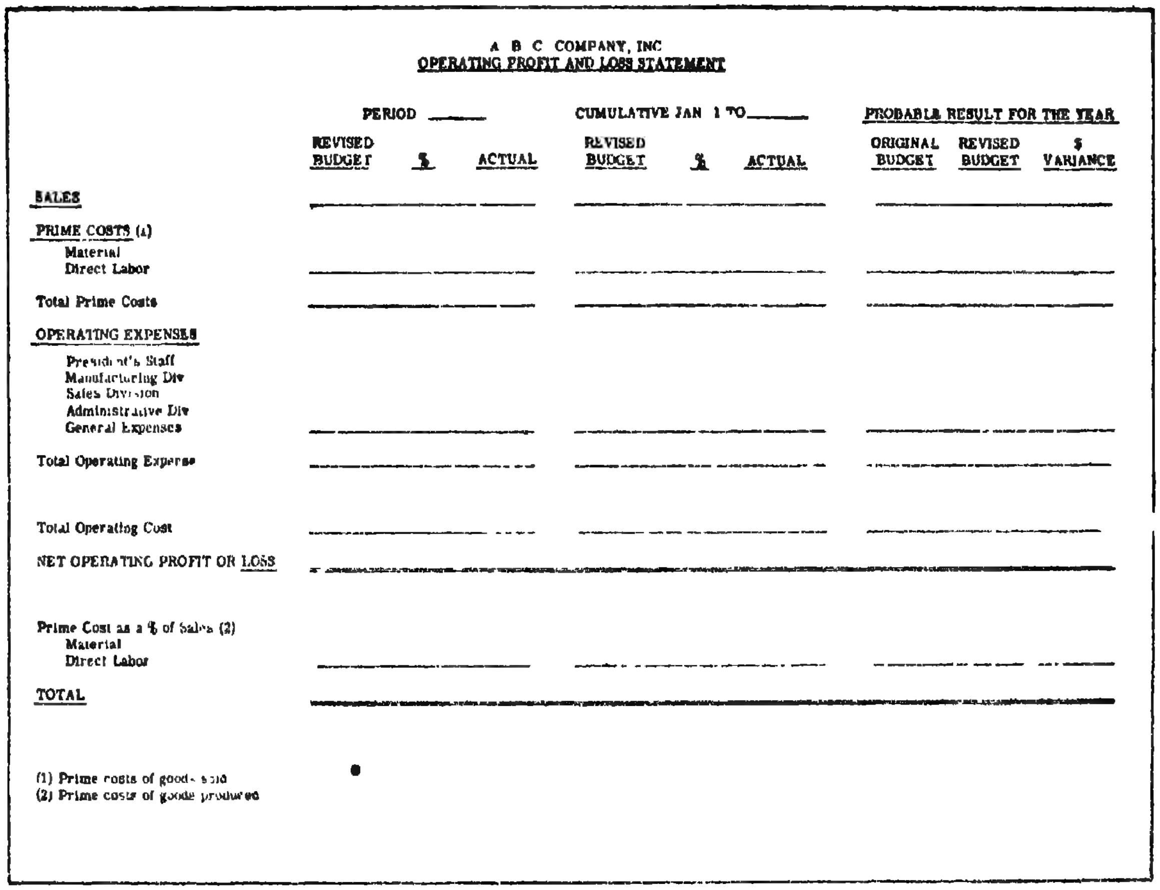
In the company chosen as an illustration, the budget is prepared by a budgeter whose office is part of the control department (see Art. 6 2 for the organization of such a department). The company is a middle-sized one, employing up to 600 workers, manufacturing and selling its own products to jobbers and to retailers. About 200 different items are sold to more than 5,000 customers. Sales are about $5,000,000.

The yearly sales forecast, item by item, expressed in physical units, is prepared by the sales department in October and translated into dollar values by the control department. The control department, acting on the basis of the sales forecast and of high-policy instructions received from top-management (maximum size of inventory, borrowing policy, and so on), prepares the production program for the following year, week by week, department by department, expressed in direct-labor hours. On the basis of this program, the budgeter prepares the budget, in cooperation with department heads. The direct-labor and direct-material expenses, and also the general expenses over which the department heads have no control, are estimated by the budgeter himself. The budget is ready during the first half of December and is presented for approval by the executive committee of the company. The form used is simply a budgeted profit and loss statement for the period ending December 31 of the following year.

After approval of the budget by the executive committee, the department heads are notified. They are instructed to remain within the limits of the budget, under their own responsibility. If there is a need for more money in their department, they will request an additional appropriation at the next budgetary revision. In this company, the budget is revised every four weeks. In case of emergency, the department heads may receive an exceptional appropriation from their vice-president. In this company, this actually happens very seldom.

The sales forecast is revised only when actual orders depart drastically from the budgeted orders, or when the sales department requests such a revision. In such a case, the production program is not necessarily altered. The final decision concerning a change in the production program is taken by the executive committee. The policy is to absorb, by increase or decrease of inventory, rather than by change in the production program, any variance of actual sales as compared to the sales forecast, unless such a policy proves to involve excessive risk or practical impossibility. If this should be the case, a general revision of the production program is ordered. This again is an exceptional procedure. Minor adjustments for each individual item within the framework of the production program are matters of routine handled by the control department.

The expense budget is revised systematically every four weeks. The depart-



A B C COMPANY, INC
OPERATING PROFIT AND LOSS STATEMENT

	PERIOD ____			CUMULATIVE JAN 1 TO ____			PROBABLE RESULT FOR THE YEAR		
	REVISED BUDGET	%	ACTUAL	REVISED BUDGET	%	ACTUAL	ORIGINAL BUDGET	REVISED BUDGET	$ VARIANCE
SALES									
PRIME COSTS (1)									
Material									
Direct Labor									
Total Prime Costs									
OPERATING EXPENSES									
President's Staff									
Manufacturing Div									
Sales Division									
Administrative Div									
General Expenses									
Total Operating Expense									
Total Operating Cost									
NET OPERATING PROFIT OR LOSS									
Prime Cost as a % of Sales (2)									
Material									
Direct Labor									
TOTAL									

(1) Prime costs of goods sold
(2) Prime costs of goods produced

FIG. **16.3** BUDGET CONTROL FORM (OPERATING PROFIT AND LOSS).

ment heads must request an increase or a decrease in their appropriations and are held responsible for overestimating their needs as well as for underestimating them.

Every four weeks, the budgeter presents to the executive committee:

1. The requests for revision for the following four-week period, starting two weeks from request date.

2. The results of the last period (ending two weeks before). The forms used, which support each other, are shown in Figs. 16.3 and 16.4. Notice that these forms apply to the period under consideration, to the cumulative results since the beginning of the year, and to the probable final result at the end of the year. The forms show two distinct budget variances:

1. *The variance between the original and the revised budget.* This variance is actually the responsibility of the executive committee. In a well-budgeted business, it should be only a few per cent (see Art. 4.2 and Table 16.1). When budgetary control is at its beginning in a given company, this variance is bound to be more substantial, at least during the first few years. A maximum variance of 8 to 10 per cent, even during these first years, is a realistic goal in a well-managed business in a reasonably "normal" year.

2. *The variance between the actual expense and the revised expense budget.* This variance should be zero, except for the case of proved emergency. Any variance above 1 or 2 per cent should be automatically investigated by the budgeter, who should present his findings to the executive committee for decision. Such variances are due to over-expenditures by department heads and they must be prevented if budgetary control is to be meaningful and rewarding.

This whole procedure of expense control and adjustment is greatly acceler-

A B C COMPANY, INC
DEPARTMENTAL & GENERAL EXPENSE
BUDGET

	PERIOD # ____			CUMULATIVE JAN. 1 TO ____					PROBABLE EXPENSE FOR THE YEAR		
	REVISED BUDGET	%	ACTUAL	ORIGINAL BUDGET	%	REVISED BUDGET	%	ACTUAL	ORIGINAL BUDGET	%	REVISED BUDGET
PRESIDENT'S STAFF											
Design											
Mold											
Total Pres Staff											
MANUFACTURING DIVISION											
Plant											
Engineering											
Plant Maint											
Inspection											
Receiving											
Shipping											
Control											
Total Mfg. Division											
SALES DIVISION											
Selling											
Packaging											
Sales Prom											
Order & Credits											
Total Sales Division											
ADMINISTRATIVE DIVISION											
Administration											
Purchasing											
Personnel											
Building Service											
Bldg Maintenance											
Total Admin Division											
GENERAL EXPENSES											
Mfg Expense											
Sales Expense											
Admin Expense											
Other Exp & Income											
Total General Expense											
TOTAL DIVISION & GENERAL EXPENSE											

FIG. **16.4** BUDGET CONTROL FORM (DEPARTMENTAL AND GENERAL EXPENSE).

ated and facilitated by the use of a systematically coded chart of accounts kept at all times in accordance with the organization chart of the company.

4.8 SYSTEMATIC CODING OF EXPENSE ACCOUNTS

Budgetary control should be based on a proper classification of expense accounts, so designed that:

(1) Each item of departmental expense is clearly classified according to the nature of the expense.

(2) The responsibility for each departmental expense is clearly defined.

(3) The cross-summarization,* at the plant level, of each item of departmental expense can be easily accomplished.

To serve these three purposes, a chart of accounts should be prepared that is:

(1) Sufficiently detailed, so as to classify each item of departmental expense according to its nature.

(2) Kept identical in its divisions with the organization chart, so as to reflect clearly each department head's responsibility.

(3) Systematically coded, so as to

* By "cross-summarization" we mean the summarization for all (or some of) the departments of one specific item of expense as distinct from the summarization of all expenses, department by department. For instance, the overtime expense in each department is part of the summarization when added to the other departmental expenses and part of the cross-summarization when added to the overtime from all (or some) other departments. Systematic coding facilitates the use of accounting machines.

TABLE **16.2** THE W COMPANY—CHART OF ACCOUNTS (Extracts)

PART I

1000 to 1999	Assets
2000 to 2799	Liabilities
2800 to 2899	Capital Accounts
2900 to 2999	Surplus Accounts
3000 to 3999	Sales Accounts
4000 to 4999	Prime Cost Accounts

PART II

5000	Research Department
5011	Administrative Salaries
5013	Operating Salaries
5014	Overtime
5021	Miscellaneous Supplies and Expenses
5041	Outside Services
50411	Outside Service—Model Making
5051	Travel Expense
5500	Inspection Department
5511	Administrative Salaries
55131	Supervisory Salaries
55132	Materials Handling
55133	Roving Inspectors
55134	100% Inspectors
55135	Salvage
5514	Overtime
5521	Miscellaneous Supplies and Expenses
5551	Travel Expense

PART III

8900 to 9999	General Factory Expense Accounts— Other Non-departmental Expenses— Non-operating Expense and Income

facilitate the cross-summarization of each item of expense.

These principles can be best illustrated by describing an actual case. Table 16.2 shows an extract of this chart of accounts. The advantage of this system of numeration is to facilitate the listing at any time of additional accounts, or the subdivision of accounts, without changing the general pattern of the chart.*

As seen in Table 16.2, the numbers 1000 to 4999 and 8900 to 9999 are respectively used to identify balance-sheet accounts (Part I) and non-departmental accounts (Part III). Numbers 5000 to 8899 are assigned to departmental expense accounts, which will now be described in greater detail.

Part II in Table 16.2 reproduces the accounts assigned to two departments selected at random, the research department and the inspection department. The first two digits of all accounts in the research department are 50, which identify the research department. The inspection department is identified by the group 55. The last two digits (11 for administrative salaries, 14 for overtime, etc.) are common to the same item of expense in all departments. Thus, in the inspection department, overtime is numbered 5514. By adding all accounts whose first two digits are 55, one obtains the total expense for which the chief inspector is held responsible. By adding all accounts whose last two digits are 14, one obtains the total overtime expense for the plant as a whole. (Cross-summarization, see footnote, p. 1098.) The use of accounting machines is obviously greatly facilitated.

When a department requires a clas-

* See Dewey-Decimal Classification and Relative Index, 1952.

sification of expense that is not to be found in the other departments, one digit is added to one of the general categories or to a related category of expense. For instance, in the W Company, the "13" accounts, as seen in Part II, Table 16.2, identify operating salaries. It was found that cost control in the inspection department would be improved by accounting separately for the wages and salaries of supervisors, material handlers, roving inspectors, 100 per cent inspectors, and salvage workers. The accounts 55131 to 55135 were created to serve this purpose. The accounting machine, ignoring the fifth digit, will still cross-summarize such subdivisions as being all included in the "13" category (operating salaries).

Whenever the organization chart changes because of the creation of a new department or the consolidation of two departments, the chart of accounts is modified accordingly.

5. OTHER BUDGETS

5.1 CASH BUDGET: GENERAL PRINCIPLES

One of the first rules of business is that the payroll must be met on Friday night. Otherwise, the plant might just as well remain closed on the following Monday. It would be of no help to tell the workers that the production has already been sold on credit at a very good profit for future delivery They want cash and they want it on Friday night.

The cash situation, although closely related to the other activities of the business, should nevertheless be considered for itself. Sales on account, for instance, may be highly profitable; they do not mean immediate cash. Even made at a loss, cash sales may sometimes seem to be preferable.

The cash budget, like the other budgets already studied, is nothing more than a reasonable estimate of a future performance. The budgeter, in this case, forecasts cash receipts and cash disbursements. The cash on hand at the end of any future period, the determination of which is, in the final analysis, the purpose of cash budgeting, is equal to the cash on hand at the beginning of the period plus (or minus) the difference between cash receipts and cash disbursements during the period.

Yet, because of the very special requirements of the cash equilibrium, which is closely but only indirectly related to the final profit or loss made by the business, cash budgeting presents problems of its own that are substantially different from the ones considered in the previous articles. These special problems are essentially related to two fundamental characteristics of cash budgeting:

1. *The timing is inelastic* Low sales during a given week may be due to accidental circumstances and may be compensated by the high sales of the following week This means that the timing of the sales forecast is elastic Cash shortages, on the contrary, are always very troublesome and may be fatal to the business even if they are of short duration. The timing of the cash budget is inelastic

2. *The values are subject to qualifications.* A dollar of expense is a dollar of expense—no more, no less. The budgeter is not concerned with the recipient of the dollar when he is budgeting expenses Nor, when he is budgeting sales, is he concerned with the person of the buyer. When it comes to cash, the budgeter handles values that are of a relative character. Some cash receipts are doubtful, some cash disbursements are absolutely mandatory, others may be deferred. The budgeter cannot readily compare each dollar of receipt or disbursement with any other dollar of receipt or disbursement. Their values are not always interchangeable nor can they always be balanced; they are subject to qualification.

Although these two fundamental characteristics of cash budgeting (the inelasticity of timing and the fact that values are subject to qualifications) create new and special problems for the

budgeter cash budgeting is an inherent part of a well-balanced budgetary control.

Even though limited to sales, inventory, production, and expense budgets, budgetary control will no doubt constitute an improvement upon a non-budgeted business. At the same time, the lack of cash budgeting will be either dangerous or expensive.

If the working capital is just about what is needed, cash shortages are bound to occur, one day or another. These shortages are dangerous.

If, on the contrary, the working capital is so abundant that the business just does not have any cash problem at all, the chances are that such a business could be run with substantially less working capital by budgeting the cash. The excess working capital could then be used for other and more remunerative purposes. To ignore such a possibility is expensive.

Such are the reasons why the need for cash budgeting is generally recognized by business organizations.

Although there are many notable exceptions to this rule, the rule is that cash budgeting should be part of a whole procedure of budgetary control. To have a cash budget without a reliable expense budget is not advisable. If, as it should be, the cash budget is associated with a sales forecast, a production program, and an expense budget, the estimates of cash receipts and disbursements can be made on a scientific basis.

An income, in the accounting sense of the word, does not mean an actual cash receipt. In like manner, a disbursement, at least in its timing, is distinct from an expense.

Thus, there is a need for a close analysis of the precise timing and the true character of the financial facts, even though the cash budget is based on the expense budget. (If capital expenditures are considered, they will be included in the cash budget as a separate project.)

The cash budget is generally prepared in two distinct steps:

1. *A long-range cash budget.* This statement is a study of the cash situation for the whole year. It is prepared before the beginning of the year and is part of the general planning for the year. As explained above (see Arts. 3.1 and 3.3), cash requirements are among the decisive factors to be considered when deciding upon the production program. In fact, when the production program is presented for approval, it should be supported by a long-range cash budget.

2. *A short-range cash budget.* This statement is a study of the cash situation for a coming period, generally a four-week period. It is established within the framework of the long-range budget.

The methods to be followed in the preparation of both the long-range and the short-range cash budget are similar. The difference between the two is essentially that the first one is a preliminary estimate and the second one a more precise forecast. The first one should allow for greater flexibility; the second one can afford a closer budgeting.

Essentially, in both cases, the budgeter attempts to estimate the probable cash receipts and disbursements for the period (one year or four weeks), basing his estimates on the sales forecast, the expense budget, the habits of the trade in paying invoices, and the policy of his own organization in meeting its commitments. He will also take into account the probable influence of general economic conditions, which may either accelerate or slow down the future payments. The principles involved will now be reviewed.

5.2 CASH BUDGET: FORECAST OF RECEIPTS

1. *Collection of notes receivable.* The payment of a note on due day is mandatory for the maker. The sanction is the *protest*, a rapid procedure that starts at the very minute a note, while due, remains unpaid. Since such a procedure is very damaging to the credit of the maker, a note is normally paid on due day. Therefore, unless special information is received, indicating that the maker is in a difficult financial

position, the budgeter will consider the notes payable as a definite cash receipt on the day on which the notes are due. Their collection is considered as a certainty.

2. *Collection of accounts receivable.* Such is not the case for the collection of accounts receivable. Unless the business is conducted under exceptional conditions, there is no guarantee that an account receivable will be collected on an absolutely precise day. A week's or even a few weeks' delay after due date is to be expected, a disturbing factor in the matter of cash budgeting, the timing of which is inelastic, as has already been emphasized.

If the number of accounts is sufficiently great to justify an application of the statistical concept of probability, the budgeter will endeavor, on the basis of past collection experience, to determine the amount he is reasonably sure to collect during a given period. It will generally be possible to find a stable and reliable relationship between the sales of a given month and the cash receipts of the following two, three, or four months. Attention should be given to the influence of seasonal factors, to the influence of general economic conditions, or to the influence of accidental or local happenings (a strike in a major industry, or local strikes, or an election period, etc.).

If the budgeter is in doubt, it will be wise policy to make a conservative estimate of the collection considered as reasonably certain and to consider the remaining part as a safety factor (see Art. 5.4).

3. *Cash sales.* By using similar methods, the budgeter will determine what part of sales is usually made on a cash basis. The ratio cash sales to sales on account, adjusted for seasonal variations and economic or other changes, is applied to the sales budget to determine the cash sales receipt expected.

4. *Cash discount taken.* If it is taken into consideration, the corresponding cash disbursement (anticipated payment of accounts, see below) is also being budgeted.

5. *Sales of securities.* This refers to the sales of stocks and bonds in the company's portfolio.

6. *Miscellaneous receipts.* Among the items generally found are the following:

Interest received (banks and notes).

Property rental income.

Dividends received (on stocks owned by the business).

Royalties and license fees.

Reimbursement of a loan, etc.

Transfer from subsidiaries.

Bank loans, with or without collaterals.

Bond issue.

Mortgage on real estate.

5.3 CASH BUDGET: FORECAST OF DISBURSEMENTS

1. *Payroll.* The direct-labor budget and the factory-expense budget provide a reliable estimate of the payroll. Slight variations due to bonus computation, possible overtime, and so forth, should be expected. This disbursement is generally made each week.

2. *Salaries (employees, salesmen, executives).* The factory, selling, and administrative expense budgets provide a reliable estimate in similar conditions, with the possibility of substantial variations, due, especially, to the irregular pattern of some selling expense (salesmen's commission, traveling expense, etc.). This disbursement is generally monthly.

3. *Notes payable. Redeemable bonds. Interest. Sinking-fund installments.* These have a mandatory character. Reference is made to what was previously said concerning the notes receivable. The amount to be paid is always known accurately and so is its timing.

4 *Accounts payable.* Although the payment of an invoice on due date does not have the same mandatory character as that of a note or a bond, undue delays are damaging to the organization's good standing. Due payments will therefore be budgeted, as a rule, as a definite cash disbursement. Their amount and timing are generally known accurately. Anticipated payments for the purpose of discount-taking will be taken into account

if they are in accordance with the organization's policy. If the cash position permits, it is always good policy for a business to take advantage of a discount for anticipated payment of accounts. Such discounts are generally very substantial (2 per cent 10 days—net 30 days, which is the equivalent of about 35 per cent interest a year). Although they may occasionally be an expensive way for the seller to collect his accounts, they furnish the buyer a very good use for his available cash. Cash budgeting, by giving an accurate advance notice of cash availability, will make it possible for a business to take full advantage of such discount offerings.

5. *Dividends declared.* After the date at which they have been declared payable, the company's dividends become a definite commitment.

6. *Royalties and license fees.* These disbursements are due on a definite date and should be budgeted as such. The estimate is made on the basis of the production or sales budget if the amounts depend upon the volume of production or sales.

7. *Taxes.* The various taxes (payrolls, old age, unemployment, city, state, and federal) are generally due on a definite date. Their amount is usually known well in advance, so that they do not create any special cash-budgeting problems.

8. *Cash purchases.* Such disbursements are generally minor ones. They usually take the form of petty-cash fund replenishments.

9. *Investments.* These are the important items of optional disbursement. They may take the form of purchase of stocks, loans, and so forth. In fact, if a company enjoys for a substantial period of time an excess of available cash, such investments become an important part of the company's financial management. In an insurance company, for instance, the problem of finding a remunerative and safe investment is certainly one of the most serious problems faced by management.

10. *Transfers.* If a company controls a subsidiary or is controlled by a parent company, the transfer of cash is a current item. In the case of a subsidiary, it often is the rule that all the cash available in excess of a determined amount should be scheduled for transfer at prescribed times.

11. *Reserves and surplus.* The word "reserve" is indiscriminately used in accounting to cover situations which, from the point of view of cash budgeting, are fundamentally different. Two classes of "reserves" should be distinguished:

a. *Valuation reserves that do not involve any cash transaction.* Examples are the reserve for depreciation and the reserve for bad debts.

The depreciation expense is an accounting expense that reduces the book profit (or increases the book loss) to take into account the fact that the income of the business is partly made by using, at no cost for rent, equipment previously purchased and paid for. The capital expenditure thus involved in the past should be reimbursed over a period of years. This reimbursement, however, is not made in cash form. The depreciation expense is an accounting reduction of the profit and is actually balanced by the accounting credit to a reserve account called reserve for depreciation. No debit or credit is involved as far as the cash account is concerned.

Later on, after a piece of equipment has been sold or scrapped, the reserve for depreciation concerning this piece of equipment is balanced and the account is closed. At no time is cash involved.

The reserve for bad debts (or for doubtful accounts) is periodically credited by debiting a bad-debt expense account. This reserve account is debited at the time it becomes evident that an account receivable will not be collected. The cash account is not involved, in either the debit or credit entry.

b. *Reserves that do involve cash transactions.* Such reserves are essentially the reserves for contingencies. For example: A business is involved in a patent suit. No one can tell what the court decision will be. It is known, however, that, should the business lose the case, it would mean paying a given

amount of money that can be estimated with a certain degree of accuracy. This amount somehow threatens the cash available. This threat will be treated by the budgeter as a probable expense and will be budgeted for the amount and for the time he thinks appropriate. After the case has been settled, the exact amount involved is known and is substituted for the estimate

If the accounting is kept on an accrual basis (as is now usual in a business organization), an accrued expense that is not yet paid, a prepaid expense that was not yet due, an accrued income not yet received, or an already cashed income that was not yet earned are all accounted for in special deferred or accrued-items accounts.

Such accounts do not in themselves involve any cash receipt or disbursement, but they are used by the cash budgeter for a final adjustment of his estimate of future cash transactions.

5.4 CASH BUDGET: SAFETY FACTOR

As was previously mentioned (Art. 5 1), the cash requirements are characterized by:

1. Their rigidity. Some payments are mandatory; their timing is unelastic

2. Their uncertainty. Values are subject to qualifications All debtors are not equally reliable.

To master the complex and potentially dangerous situation created by such factors, the cash budgeter will do well to introduce a certain margin of safety into his budget. The following elements may be considered:

1. *Cash on hand*. The cash on hand in the various banks with which the organization conducts business is a reservoir of cash. The size of this reservoir should be commensurate with the element of uncertainty involved in the cash budget; seasonal factors and uncertainty of the general economic conditions will be taken in account, as will the existence or nonexistence of optional sources of cash.

2. *Optional receipts*. An additional reservoir of cash results from the existence of optional cash receipts such as lines of credit, securities on hand that can be sold or stock that can be issued, and properties that can be mortgaged.

3. *Postponable disbursements*. The existence of payments that can be deferred without endangering the credit of the organization are an additional element of flexibility. Such are the payments related, for instance, to a raw material purchase program intended for stockpiling, which can be deferred or canceled, and equipment purchases and other capital expenditures, which can be postponed. Whenever the cash situation is such as to warrant careful consideration, such elements of flexibility should be made part of the statements presented.

5.5 CASH BUDGET: PRESENTATION

Figure 16 5 reproduces a cash budget as presented in a given organization. This form relates to the same business as the one described in Art. 4 7 and is also reproduced as a simple illustration for the guidance of the reader, rather than as a form that can be used in any other business than the one for which it was specifically designed.

In this particular company, the cash budget is established first for the whole year on a tentative basis and submitted at the time the production program is presented for approval. It is then established on a four-week basis within this general framework and is presented to the executive committee in the form shown in Fig. 16 5. As seen in Fig. 16 5, the budgeter presents both the actual and the budgeted figures for the preceding periods and the budget for the following one. The cash budget is submitted to the executive committee two weeks before the four-week period under consideration.

5.6 CASH BUDGET: ITS DYNAMISM

Cash budgeting is a dynamic venture. It should not be considered by the budgeter as a simple statement

A B C COMPANY, INC
BUDGETED CASH RECEIPTS AND DISBURSEMENTS

	PERIOD # ____			PERIOD # ____	PERIOD # ____
	BUDGET	ACTUAL	VARIANCE	BUDGET	BUDGET
SALES FORECAST					
CASH COLLECTIONS (Accounts Receivable)					
EXPENDITURES					
Accounts Payable & Accruals Jan 1, 195__					
Federal Income Tax Liability Jan 1, 195__					
Total Liabilities as at Jan 1, 195__					
Capital Expenditures					
Raw Material					
Direct Labor					
Departmental Salaries					
Departmental Expenses					
General Expenses					
Rent					
Payroll Deductions					
Total Operating Expenditures					
CASH INCREASE OR DECREASE					
OPENING CASH BALANCE					
ANTICIPATED CASH BALANCE (Before Bank Loans and Repayments)					
BANK LOANS OR REPAYMENTS					
ANTICIPATED CASH BALANCE (After Bank Loans and Repayments)					

FIG. 16.5 CASH BUDGET CONTROL FORM.

of facts or as only a forecast of what is in the making. If the probability is that the future situation is not going to be a satisfactory one, the first duty of the budgeter is to suggest a change in policy. This is true for all phases of budgetary control, although cash budgeting offers a more clear-cut opportunity of showing the potential dangers of a given situation. Although the budgeter will have to use his ingenuity to remedy each particular situation, the efforts toward an improvement of the cash situation should, in general, be exercised in three main directions:

1. *A reduction or a postponement of capital expenditures* when they are not compensated for by special financing, such as bonds or loans.

2. *A reduction of inventory.* The smaller the inventory, the more working capital. The reduction should be attempted for the three kinds of inventory:

a. Raw material.

b. Goods in-process.

c. Finished goods.

It will be found that a reduction of finished-goods inventory is related to a reconsideration of the channels of distribution. If the company operates its own sales branches, a careful analysis of inventory turnover for each branch should be made. Comparison between the branches will often bring to light unwarranted discrepancies and will be the origin of spectacular improvements.

When undertaking such a comparative study, it is well to remember that the inventory turnover does normally increase with sales. Two branches of different size are not to be expected to reach the same turnover ratio.

A reduction in the other two sections of the inventory—namely, the goods in-process and the raw-material inventories —is to be sought by improving the production control and scheduling procedures in relation to the sales forecast (see Art. 3.1). Here again, spectacular

improvements have been shown in many organizations.

3. *An acceleration of collections.* Finally, a substantial improvement of the cash position will result from an acceleration in the collection of the accounts receivable. The delays in collection are sometimes due to unavoidable circumstances. More often, especially in larger companies, they are the result of a certain relaxation in control. A systematic policy of improving the situation, based on a constant comparison between the various branches concerned, may greatly improve the situation.

4. *Improving the cash position: An actual case.* One company recognized that its cash position, as revealed in the cash budget, was not satisfactory. It decided to attempt to improve the situation by taking successively some of the steps previously described.

It took under consideration a reduction of raw-material and goods-in-process inventories by an improvement of production scheduling and control. The reduction of capital expenditures was not an actual problem. The reduction of the finished-goods inventory and the reduction of the receivable collection period, based in both cases on systematic control and guidance of the sales branches, was attempted. The following results were obtained in a nine-month period:

The company manufactures consumers' and industrial goods and sells about $30 million a year through about 150 sales branches. The managers of these branches were requested to make a special effort to increase their inventory turnover and to accelerate the collections. They were advised that a close control would be established to check the results obtained by them.

Over this nine-month period, the average inventory turnover was increased by 50 per cent (from 3 to 4.5), and the average collection period was accelerated from a 50-day average to a 38-day average. As a net result, the actual cash on hand increased by $5 5 million, almost 20 per cent of the sales volume.

5.7 CAPITAL EXPENDITURES BUDGETS

The budget of capital expenditures is related to those disbursements, and the corresponding receipts, that are not part of the profit and loss statement. This includes such disbursements as additions, improvements, and replacements to plant and equipment, capitalized major repairs, and capitalized major research programs. The corresponding receipts result from long-term bank loans, bond or stock issues, and utilization of surplus.

The distinction between capital and current expenditures is not always clear-cut. For instance, the repair and research expenditures that will be capitalized will often be influenced by what is permissible for income tax purposes. The reader should therefore be aware that opinions of accountants differ on whether or not to capitalize certain borderline items Moreover, there is great variability in actual industrial practice in this matter.

There are, both in theory and practice, capital-expenditure, major-repair, and capital-research budgets. The general principles of budgeting involved are fundamentally different from the ones previously described for current expenditures and incomes.

Perhaps the most significant characteristic of such capital-expenditure budgets is that each project constitutes a distinct venture that is considered for itself in each of its elements (expense, income, gain, degree of urgency, and so forth).

The purchase of this or that equipment, the major repair of this or that machine, the beginning of this or that research are each a special project. There are generally as many budgets as there are special projects. Each of these special budgets should provide for its expenditures and also for its income.

The income will generally result from an advance made to the project considered as an accounting entity by the business as a whole. The cash may originate either from the reserves of the busi-

ness or the current profit or from a loan specifically contracted for the purpose.

Before a final decision is made, management should be in a position to appreciate:

1. The total expenditure involved.

2. The possible source of income or funds to cover such expenditures.

3. The ultimate gain that will probably result from the project.

4. The period of amortization and its effect on future current expense.

Thus, the budgeter will recognize the need for four distinct phases in capital-outlay budgeting, which will now be described.

First phase: project approval Generally, the mere estimate of a capital outlay, if it is to be reliable, requires time, effort, and preliminary expenses. Therefore, the first step is to submit for consideration by the proper authorities a proposal of the project itself. A very approximate estimate may be given at this time, together with the motives for considering the project at all. This approximate estimate will not always be available. For instance, there may be no way to know with any reasonable degree of approximation the cost of a research project. In some cases, it is desirable to obtain an estimate of how much it would cost to have a specialist prepare the project estimate (for instance, architect and engineer fees involved in the planning of a new plant). In most cases, it will be possible to secure an adequate first estimate by simply inquiring from the eventual supplier (plant builder, equipment manufacturer, etc.).

Second phase: estimate approval. The final estimate should be based on definite and reliable figures. If the capital outlay involves the replacement of existing equipment or the choice between two or more possibilities, the relative value of the alternatives should be clearly shown.*

If research is involved, the probable or possible gain should be shown as accurately as possible. If a major repair is considered, its cost should also be compared with the cost of replacing the equipment, due account being taken of the effects on maintenance cost.

The estimate approval by management indicates approval of the project as a matter of principle. It does *not* imply authorization to proceed. The fundamental reason is that there is a gap between a sound idea and the possibility of realizing it.

Third phase: authorization of the project This gap is bridged by the authorization given to proceed. Such an authorization involves a determination of the ways and means to finance the project (by loan, by using reserves, etc.) The relationship to the cash budget is obvious. If the project is actually a succession of individual projects, a partial authorization may be given. This is sometimes a dangerous procedure, since it may create a *fait accompli* with respect to the other parts of the project Management, later on, may be more or less forced to authorize them, lest the benefit of the first efforts be entirely or partially lost

If a substantial period of time elapses between phase 2 (approval of estimates) and phase 3 (authorization of the project), it will be a good policy to revise the original estimates.

The authority responsible for approval of the estimate or authorization of the project varies with the size of the project and the traditions of the organization As a rule, any capital outlay of importance requires approval by the board of directors. Unless the board's authority has been formally delegated, it should always be consulted on such matters.

Fourth phase: follow-up. The follow-up serves a double purpose:

1. It should keep management informed of the progress of the work and of the conformity of actual execution to the budget. The following procedure is used on this point in one organization (an oil company) that has engaged in extensive improvement pro-

* For more details, see Section 3, Engineering Economy, of this Handbook.

grams in recent years, involving very substantial capital expenditures:

> Charges to each project are accumulated on job cost sheets by the plant property section. When it becomes evident that a job will be overrun, a supplementary request must be submitted beforehand showing complete details concerning the extent and reason therefor. Such requests must be approved by the same level of management who approved the original request. Underruns below a certain percentage of the amount originally approved must also be covered to explain why authorizations were not fully spent.
>
> In this connection one cardinal rule might be emphasized, and that is that unexpended balances remaining at the close of a project cannot be expended on another project by transfer or otherwise. To permit such a practice would serve to defeat the purpose of the procedure which is to control each individual job in relation to the amounts authorized or budgeted.
>
> The work required in connection with the preparation of appropriation requests, the maintenance of job cost sheets and the submission of the various status reports described above are handled by the plant property sections at each plant, who are also responsible for the maintenance of all property, plant and equipment records. The budget section at the home office is largely interested in the divisional and consolidated summaries which are used for corporate planning and control purposes.

Such a procedure clearly illustrates the principles developed earlier. The cardinal rule, that unexpended balances remaining at the close of a project cannot be expended on another project by transfer or otherwise, cannot be overemphasized. If it is not strictly and even rigidly enforced, there is no justification for capital-expenditure budgeting.

2. At a later date, if production lends itself to such a presentation, the follow-up procedure should show management the ultimate gain made through the project. For instance, if new equipment has been bought, the budgeter will present a comparative statement showing the actual cost of production with the new equipment, as compared with what it was previously. If a research project has been undertaken, any saving realized through the research work should be shown as a credit to the "project" (considered as an accounting entity), which is debited accordingly with the amount of capital expenditure. It should be clear that such presentations are in the form of accounting analysis and are not included in the books of account.

In the case of the company previously taken as an example (see paragraph 1, directly above), it is the rule to establish a semiannual savings report comparing actual savings with estimated savings on each request approved to accomplish economies in operation.

6. ORGANIZATIONAL PROBLEMS

6.1 FUNCTIONAL ORGANIZATION: THE CONTROL FUNCTION

Modern industry is based on the concept of functional organization. The shoes that we wear were most likely manufactured in a plant employing some 800 workers supervised by some 50 foremen, supported by some 100 service and staff employees and technicians, and guided by about 25 executives. Acting as a team, this group of about a thousand men and women may produce during the year, infinitely more than a thousand times what any shoemaker of the last century would have dreamed of making in his whole lifetime. Yet this old-timer was able to make shoes by himself, starting with the raw material and ending with the delivery of the finished product to the customer. The chances are that no single individual among the thousand executives, engineers, employees, and workers now running the shoe-manufacturing plant would be able to make a single pair of shoes if he were left to work alone.

In this group of a thousand individuals, each has *a function* to perform, such as purchasing the raw material, selling the goods, designing the product, operat-

ing the plant, paying the workers, managing the company. No one is supposed to be able to perform more than one or at most a few of these various functions. As a rule, no one in modern industry is today able to perform all the functions involved in the manufacturing process. The reason is that the growing complexity of modern science makes it impossible for a single individual to master all the skills required in modern manufacturing. Modern industry produces by coordinating the activities of the various specialists whose skill or ability or effort is required in the manufacturing process: engineers or salesmen, janitors or managers, draftsmen or material handlers, toolmakers or assembly workers.

The performance at the proper time of all required functions results in production at a much lower cost than would be true in production by one single individual. Modern industry is based on the concept of functional organization, as opposed to industry based on handicraft.

The modern industrial organization will function properly and economically if, after all functions are clearly recognized and assigned to competent individuals, the cooperation of all members of the organization and the coordination of their efforts are properly organized.

Some functions have been recognized for many years and are generally assigned to competent individuals who are able as a rule, without encountering excessive difficulty, to synchronize their efforts with those of the other members of the team. For instance: the sales function, the maintenance function, the inspection function, and the accounting function, to mention only a few.

Until very recently, the *control function* did not receive the full recognition it is entitled to. Even today, in many organizations, the control function has not reached full maturity. It is simply considered either as an appendix of other functions, such as accounting, or as one aspect of the general duties of the executives who manage a company.

In a more progressive and rewarding concept of industrial management, control emerges as a full-fledged function to be performed by control specialists grouped in a specific subdivision of the organization, the control department.

6.2 THE CONTROL DEPARTMENT

As with all other functions in industry, there is no rigid definition of the control function.* Its scope varies with the particular needs of a given group of individuals who are associated as a team in a given business. An understanding of the function itself is based on the following considerations:

To *control* an organization is the duty of management as a whole and, in the final analysis, the duty of the head of the organization.

In a so-called "one-man" business, to control means for the head executive to make all decisions and to supervise the performance directly. Modern industry is rarely a "one-man" business. It can generally perform only if the head of the organization delegates part of his responsibility and authority to executives, who in turn delegate to their subordinates part of their authority and responsibility. In such a framework of operations, to control means:

1. To assign certain goals.
2. To compare the actual performance to the prescribed goals.
3. To draw certain conclusions from the comparison—for instance, to investigate a department, a process, or a market, to promote or demote, to reward or blame, to correct the decision taken.

The function of the control department, generally speaking, is to help management to fulfill its control duties. Thus, control will assign detailed goals to the various operating and service departments, in accordance with high-policy decisions made by management; it will follow up all performances, analyze them, and present them to management in an organized pattern in the form of reports. Such reports should be short

* For a detailed study of the control function, see Villers, *The Dynamics of Industrial Management,* Chapters 4, 5, 9, 10, and 14.

and general enough so that they can be easily read and understood and yet specific enough to be used for detailed investigations when, in management's opinion, there is a need for such investigations.

In other words, the control department operates the mechanisms of managerial control. This is true for all aspects of control: control of human relations (measured in terms of absenteeism, turn-over, grievances), or control of equipment maintenance (measured in terms of break-down or repairs), control of sales and production (measured in terms of rejects or inventory turn-over), and so on. It is also true for cost control and budgets, which are more specifically the subject of the present study.

In the absence of a control department, the management of cost control and budgets is entrusted to various departments, such as accounting, cost accounting, budget, payroll, development engineering, and industrial engineering.

It is advisable to separate the control function from the other functions performed by such departments and to centralize the control function under one department. The head of the control department may advantageously serve directly under one of the high ranking executives, a vice-president or even the president.

6.3 AN ACTUAL CASE

In one business, the control department is placed under an executive vice-president. Its functions in terms of cost control and budget are as follows:

1. It is in charge of the budget.
2. It centralizes all cost standards.
3. It follows up all expenses and compares them with the standards.
4. It prepares all managerial reports related to cost control and budgets.
5. It investigates all matters related to cost control and budgets, as requested by management.

To perform its duties, the control department, which is in charge of operating the IBM equipment, uses the services of all departments. The following examples will illustrate how the control function can be integrated with the other functions:

1. Direct-labor standards are prepared by the industrial engineer in terms of time required for each operation and are translated into dollars and cents per item by the control department.

2 Direct-material standards are prepared by control on the basis of information supplied by engineering (quantity) and purchasing (price).

3. Overhead expenses are forecast by the budgeter, who is, as previously indicated, a member of the control department.

4 Actual manufacturing costs are recorded by cost accounting, which is part of the accounting department, but analyzed by the control department, which uses them for the preparation of reports described later on (see Art. 7).

5. Other actual expenses are followed up by the budgeter on the basis of data made available by the accounting department and presented to management in the form previously described (see Art. 4 7).

In addition, the control department performs similar duties for the control of other activities not directly related to costs. Although these duties will not be described here, they include scheduling of production, follow-up of inventories, scheduling of material purchases, and personnel turn-over and absenteeism. The centralization of control, because it has made control more effective, has enabled this organization to decentralize to an unusual extent the authority and responsibility of all members of management. As a result, costs have been reduced because the origin of reducible or unnecessary expenses has been exposed and thereafter eliminated. At the same time, members of the organization have been granted a greater freedom, because the more effective control eliminates the risk involved in increased freedom of action. The members have thus regained an independence that is often lost in modern industry. They have de-

veloped a sense of individual responsibility that can be compared to that of the independent businessman.*

The managerial reports issued by the control department in the matter of cost control and budgets will now be described.

7. MANAGERIAL REPORTS

7.1 PRINCIPLES

Cost and budget reports are an aid to management.† If, however, they are too extensive or too intricate, they may either go unread or be misunderstood. Yet, if they leave loopholes open in the texture of managerial control, they defeat their own purpose.

The solution to this dilemma is in the preparation of reports in a condensed form that gives a visualization of the situation, just as maps covering large areas give an over-all view of whole continents. But such maps are never the direct product of surveying. They are based on surveys that were made on a larger scale and subsequently reduced. But the large-scale surveys remain available in their original form if more precise information is needed. In like manner, managerial reports in a condensed form are actually a synthesis of more detailed information that should be kept on hand and referred to if the over-all results disclosed by the condensed reports are, in any respect, considered as unsatisfactory, disturbing, or unexplained.

Another and very essential consideration is that the reports for management, for obvious reasons, should be reliable. Not only should they be carefully prepared and checked, but also, whenever possible, they should tie in with the documents of general accounting, which are themselves subject to auditing. If a direct tie-in is not possible, a "reconciliation" should be made.

Finally, incorporating the necessary data in a report is one thing, but making the reader grasp its meaning is often more difficult. Figures alone are generally insufficient to convey an understanding of a situation. Graphs and drawings may be useful tools but, whether reports are in graphical form or not, the essential is to provide an adequate yardstick with which actual results can be usefully compared and thus understood.

It thus appears that an effort should be made to present to management cost reports that are:

1. In a reasonably simple and condensed form.
2. Readily expandable in any direction if an investigation is desired.
3. Self-controlling.
4. Provided with a standard of performance.

How these four essential principles can be applied to actual cases will be shown later in this article, in the discussion of the various categories of cost reports for management.

7.2 REQUIREMENTS

Cost control and budgets serve three essential purposes. They enable industrial managements to:

1. Control the net profit (or loss) made by the organization as a whole.
2. Control the expenditures made by the members of the organization.
3. Control the pricing and marketing policy in relation to the unit cost of production and distribution.

The reports prepared for management will vary in each organization, and will even vary in scope, number, and form when new individuals become members of the organization or when new circumstances arise. But it is important to note that the set of cost reports presented to management should at all times fulfill the three essential require-

* For a more detailed presentation of this case study, see Villers, "Freedom and Control in a Decentralized Company," *Harvard Business Review*, March-April 1954.

† For a detailed study of managerial reports, see Villers, *The Dynamics of Industrial Management*, Chapters 14 and 17.

ments of cost control. For this reason, the cost control reports can be classified in three categories:

1. Control of the organization as a whole: *Profit and Loss Control.*

2. Control of responsible executives: *Expense Control.*

3. Control of products sold: *Unit Cost Control.*

These three categories will now be discussed in an attempt to show how the four principles previously mentioned (Art. 7.1) can best be applied.

7.3 PROFIT AND LOSS CONTROL REPORTS

Such reports may include:

1. *The break-even chart* of the company.* This chart, illustrated in Fig. 16.6, gives a simple and comprehensive picture of the whole situation. The actual trend of sales expense relationship is plotted against the forecasted trend, which was prepared at the beginning of the year and provides the standard of comparison.

The break-even chart can be used for monthly control by using one of the two following methods:

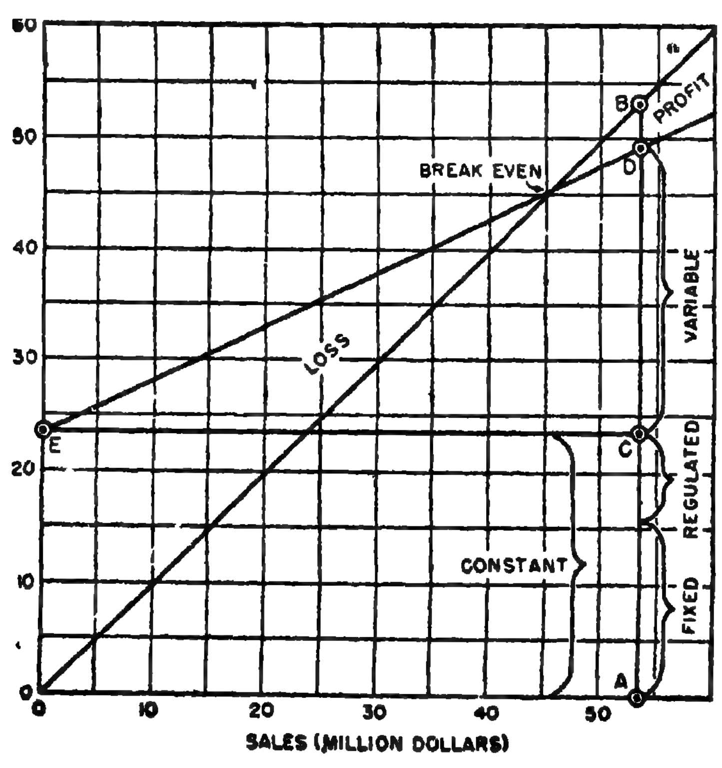
a. Compare monthly results to previously prepared monthly break-even charts based on the budget. Allocate to each month of the year its proper share of the total yearly constant expense, with the slope of the variable expense trend remaining generally the same throughout the year.

b. Or conversely, use the actual expense figures as they become available to forecast an adjusted yearly trend that can be usefully compared with the original forecast, prepared on an annual basis.

Whichever method is used, the ultimate purpose is to compare an actual sales expense trend to a standard trend, an actual profit to an anticipated one, an actual break-even point to the expected one. If the comparison reveals only minor or easily explained discrepancies, management can be satisfied that the business is progressing as expected.

* The break-even chart was first developed by Walter Rautenstrauch. For a detailed study of its application, see Rautenstrauch and Villers, *The Economics of Industrial Management.*

FIG. 16.6 THE B.E. COMPANY BREAK-EVEN CHART.



Otherwise, investigations will be in order.

To show the tie-in of the break-even chart with general accounting figures, it is advisable to reconcile the reported total cost (regulated, fixed, and variable) with the total expense figure of the books of accounts.

2. *The profit and loss budget,* described above (see Art. 4.7), will also be presented whenever available. Less condensed a statement than the break-even chart, it usefully supplies more detailed information on *why* the profit is not as expected. If it is prepared in accordance with the recommendations given in Art. 4.8 with reference to the chart of accounts, it will also determine the responsibility of each executive concerned.

This budget is presented before the beginning of the year and is followed up in monthly reports of actual profit or loss. The original budget figures are the yardstick against which actual data can be usefully compared. The actual profit or loss shown in this report may be different from the figures shown in the accounting statement, which includes accrued income and expense and other adjustments. If the discrepancy is substantial, it should be explained and accounted for.

If the actual profit (or loss) is different from the expected one, a careful reading of the report will generally disclose which divisions of the business are responsible for the discrepancy. If a further investigation is in order, an analysis of profit variance should be made.

3. *Analysis of profit variance.* The method to follow is to go systematically over all assumptions and forecasts that have been made at the time the break-even chart was constructed, or to go over the budget originally prepared, and to compare actual detailed figures with the estimates that were used as a basis for the forecast. For instance, compare:

a. *Actual expenses to budgeted expenses,* starting with large groups (manufacturing, selling, administrative) and analyzing any discrepancy in details (material expense (price or quantity), departmental expense, wage changes, overtime, time lost).

b. *Actual selling prices to budgeted prices,* accounting for change in selling price, change in channels of distributions, change in the sales mixture. (See Art. 7.5.)

The profit variance analysis should account for the entire discrepancy between the budgeted profit and the actual profit. It is a good policy to record systematically all bases of estimates used when budgeting, so as to be able to compare actual facts and figures to the assumptions made. If such records are carefully kept, the analysis of profit variance will be greatly simplified.

7.4 EXPENSE-CONTROL REPORTS

Such reports may include:

1. *A payroll analysis report.* Such a report is not always necessary. It may or may not be justified. In one plant, there were reasons to think that labor costs were higher than they should be. There was no way, however, to say for sure how they could be reduced. Each executive concerned was sincerely convinced that someone else was responsible: the chief engineer thought that time was wasted in the production departments; the plant manager blamed the methods and also the material; the sales department which was obviously responsible for rush orders, disputed the magnitude of their impact in terms of cost.

A direct payroll analysis report, as shown in Fig. 16.7, was prepared. This report is essentially a reconciliation between the *actual direct labor payroll* and *what the payroll would have been if production had been possible at standard labor cost.* The variance must have a cause and this cause must be traced

If a control department exists in th organization, it will naturally be in charge of analyzing this variance. As seen in Fig. 16.7, the variance is to be accounted for either by wage increase or other unavoidable circumstances or by the failure of one department to

DIRECT LABOR PAYROLL ANALYSIS

WEEK ______

	THIS WEEK		SINCE JAN. 1	
I. STANDARD OPERATIONS	$	%	$	%
A. Standard rates				
Inspection				
Set-up				
Total Standard				
B. Wage Increase				
C. Variances				
1. Material				
2. Engineering and Maint.				
3. Personnel				
4. Plant				
5. Excess Set-up				
6. Control				
7. Sales				
8. Miscellaneous				
Total Variances				
II. NONSTANDARD OPERATIONS				
A. Special Productions				
9. Experim. runs				
10. Special reprocessing				
11. Experim. costs				
12. Nonstandard Inspec.				
B. Transfers				
13. Samples				
14. Repairs				
15. Design				
16. Office				
17. Inspection				
Total nonstand. oper.				
III. UNACCOUNTED-FOR VARIANCE				
Grand Total				
Acct. Dept. Adjust.				
Actual Direct Labor Payroll				

FIG. 16.7 PAYROLL ANALYSIS REPORT.

perform in such a manner that production at standard labor cost is possible. It may be:

a. The purchasing department (defective material).

b. The engineering department (faulty methods or equipment).

c. The personnel department (lack of skilled labor).

d. One of the production departments (time lost).

e. The control department (neglect in ordering material or scheduling production; excessive set-up).

f. The sales department (rush orders).

g. Any other reason to be investigated.

The variance may also be the result

of circumstances not involving any special failure to perform at standard cost, such as experimental runs, special orders, transfers of personnel.

But whatever its origin a variance has to be traced back to its cause and has to be measured in dollars and cents. If the control department assigns a certain variance to a department and the head of the department disagrees with the finding, a procedure should be provided to arbitrate the case. In fact, disagreements will very rarely arise if the organization functions smoothly.

The form shown in Fig. 16.7 ties in with the books of accounts inasmuch as it is based on a comparison of standard labor figures to actual payroll (direct labor). Reconciliations are often necessary, because of various discrepancies in time or for other causes. This is why the form provides for "accounting department adjustments."

The form also provides a space for "unaccounted-for variance," but experience shows that, for all practical purposes, the variance can almost always be accounted for when an investigation is properly conducted.

The question arises: Does it pay to go into such details? The answer will vary greatly with the organization considered. Experience suggests that such reports do pay, because they tell why and by whom any amount of money is actually spent in excess of the expected amount. Corrective measures can thus be taken and followed up.

In fact, in one organization the use of a form similar to the one shown in Fig. 16.7 actually resulted in savings at the rate of more than $40,000 a year. The cost of the weekly presentation of the report was the salary of two full-time clerks and the renting of about eight hours of IBM equipment.

2. *Other expense-control reports.* Other reports may be prepared along similar lines and based on similar principles. They should be prepared either permanently or temporarily whenever there is reason to believe that costs can be reduced by a better knowledge of their origin. Such reports may, for instance, refer to: utilization of equipment (depreciation-expense analysis), material purchase, material utilization, overhead analysis.

7.5 UNIT-COST CONTROL REPORTS

The first purpose of unit-cost control is to help in the formulation of the pricing policy; the other purpose is to serve as a guide in controlling the sales mixture, in the multi-product business. Two series of reports may thus have to be considered.

1. *Cost reports related to pricing.* A record of standard or estimated unit costs should be kept item by item. Special control reports should call attention to substantial discrepancies that affect the actual unit costs and may therefore make a reconsideration of the pricing policy advisable. If, for instance, material costs change or wage rates vary, or if the over- and under-absorbed burden account increases unduly, a report should be made to show how the actual unit costs compare with standard or estimated costs and why there is a variance.

2. *Multi-product business: the sales-mixture chart.* Some businesses sell only one product as, for instance, cement, yeast, or sugar. Other businesses sell only a few different products, and their problems of cost control, though more complex, are not fundamentally different from those of the uni-product businesses.

Today, however, most businesses sell many different kinds of products. They are multi-product businesses. Westinghouse, General Electric, General Motors, Bausch and Lomb Optical Company, duPont de Nemours, Squibb and Sons —in fact, almost all the well-known big corporations and many less-known companies are multi-product businesses.

In most multi-product businesses, each dollar of sales does not bring the same amount of profit. Some sales are more profitable than others. If the "mixture" sold is rich in products on which the profit per dollar of sales is high, the

total profit will obviously be greater for a given amount of total sales than if the mixture is composed essentially of products that bring a low profit per dollar of sales.

In many businesses, the difference in profit margins among the various products sold is such that the sales mixture is the key to success or failure. A substantially unfavorable change in the sales mixture may mean a much smaller profit than expected or even a loss when the total amount of sales is equal to or greater than the budgeted one.

Too often, management gives only second place to this problem. The figure of total sales is too often regarded as magic, although, in fact, the real goal is to sell at a profit that will keep the organization running rather than to reach an impressive volume of sales regardless of profit margins. It is therefore advisable to organize an effective control of the sales mixture in all multi-product businesses and to report periodically on the actual sales mixture sold as compared with the sales mixture one expected to sell.

Very generally, the control of the sales mixture is based on the measurement of the gross profit per dollar of sales made on each product. The gross profit is generally computed as the difference between:

1. The selling price of the product, and
2. The sum of:
   a. The direct-material cost.
   b. The direct-labor cost.
   c. A certain portion of the factory overhead, called the "burden" of the product.

This approach meets with the following objections:

1. The proportion of the factory overhead assigned to each product is determined on the basis of a decision that is unavoidably arbitrary. Whatever the care taken in choosing the best-adapted basis for apportioning the factory overhead, there is a necessarily wide margin of approximation and oversimplification.

2. The part of factory overhead that is supported by some of the products sold (let us call these the products of Group A) would have to be transferred to other products, such as those of Groups B and C, either totally or in part, should the sales mixture not include any product of Group A or should the assumed percentage of Group A products in relation to total sales be less than anticipated. The result is that to evaluate the final consequence of a change in the sales mixture—for instance, a decrease in the sales of Group A—it will be necessary to recompute the burden of all the products of the Groups B, C, etc.

3. Finally, the allocation of the burden to each product tends to cloud the fundamental issue, which is: In most businesses, some lines of product offer a distinctly greater possibility of profit than others. Other things being equal, their sales should be encouraged.

From a practical point of view, only the businesses that have introduced an effective control of the sales mixture are in a position to recognize and reward accordingly the otherwise undetected efforts of the salesman who pushes the most profitable lines as compared with the salesman who, primarily concerned with volume, sells what the customer more readily accepts.

Such are the objections to the use of gross profit for the purpose of controlling the sales mixture. Gross profit, which is the difference between the selling price and the sum of direct-labor cost, direct-material cost, and part of the factory burden, is obviously the one value to use when it comes to decisions involving expense control or pricing because it takes the overhead into account; but it is not adapted to the control of the sales mixture.

It is more convenient and effective to use instead the notion of *direct profit,* which is, for each product, the difference between the *selling price* (or the average selling price in case of multi-pricing) and the *direct cost*. It is this direct profit, usually given as a percentage of the sales dollar, that will be used as a basis for establishing the sales-mixture control. Unlike the gross profit made on

an item that includes a portion of the burden and therefore varies with the sales mixture, the *direct profit* made on an item is a stable notion. It is not, as is the gross profit, dependent on the sales mixture, which it precisely purports to control.

In addition, the notion of direct profit, precisely because it does take into account only the costs that can reasonably be assigned to a product, is in accordance with the very purpose of the sales-mixture control. This purpose, in the final analysis, is to serve as a means of controlling the net profit made by the business. Any expense that does not increase or decrease substantially when the sales mixture changes does not need to be included in the sales-mixture control, because it does not influence the net profit of the business in relation to sales-mixture changes. At the same time, any expense that does increase or decrease substantially when the sales mixture changes should be included in such a control, because the control of the sales mixture will in such a case influence the amount of net profit.

Once the direct profit to be expected on each product has been determined within a reasonable limit of accuracy, the products may then be classified on such a basis. Each group should include the products on which a comparable direct profit is made by the business. The range of variation within each group will be determined according to the circumstances and the needs of the business. It will also depend on the total range of variation of direct profit, from the most profitable to the less profitable item.

The control of the sales mixture, as soon as there is a substantial number of products, may become very complex, especially if the range of variation in direct profit is a wide one.

Yet, to be meaningful, the control of the sales mixture must detect unsatisfactory conditions as soon as they begin to develop. In other words, it must be exercised at frequent intervals. Furthermore, if the distribution is done on a wide market, it must be exercised district by district.

Such a control is greatly facilitated by the use of a graphical representation, the "sales-mixture chart." This chart and its use will be described in terms of an actual case.

A business manufactures and sells about 200 different items. The analysis of the direct profit made on each item revealed that the range of variations extended from slightly more than 20 cents to a little less than 85 cents on the sales dollar. (In fact, the company sells at three different prices: wholesale

TABLE 16.3 SALES MIXTURE OF SALES FORECAST

oup	*Direct profit pe dollar* From	*Direct profit pe dollar* To	*Per cent of total sales*
1	—	23.9	0
2	24	27.9	0
3	28	31.9	0.7
4	32	35.9	7.5
5	36	39.9	8.3
6	40	43.9	12.2
7	44	47.9	16.0
8	48	51.9	26.0
9	52	55.9	12.5
10	56	59.9	13.5
11	60	63.9	0.8
12	64	67.9	2.0
13	68	71.9	0.2
14	72	75.9	0.2
15	76	Over	0.1
			100.0

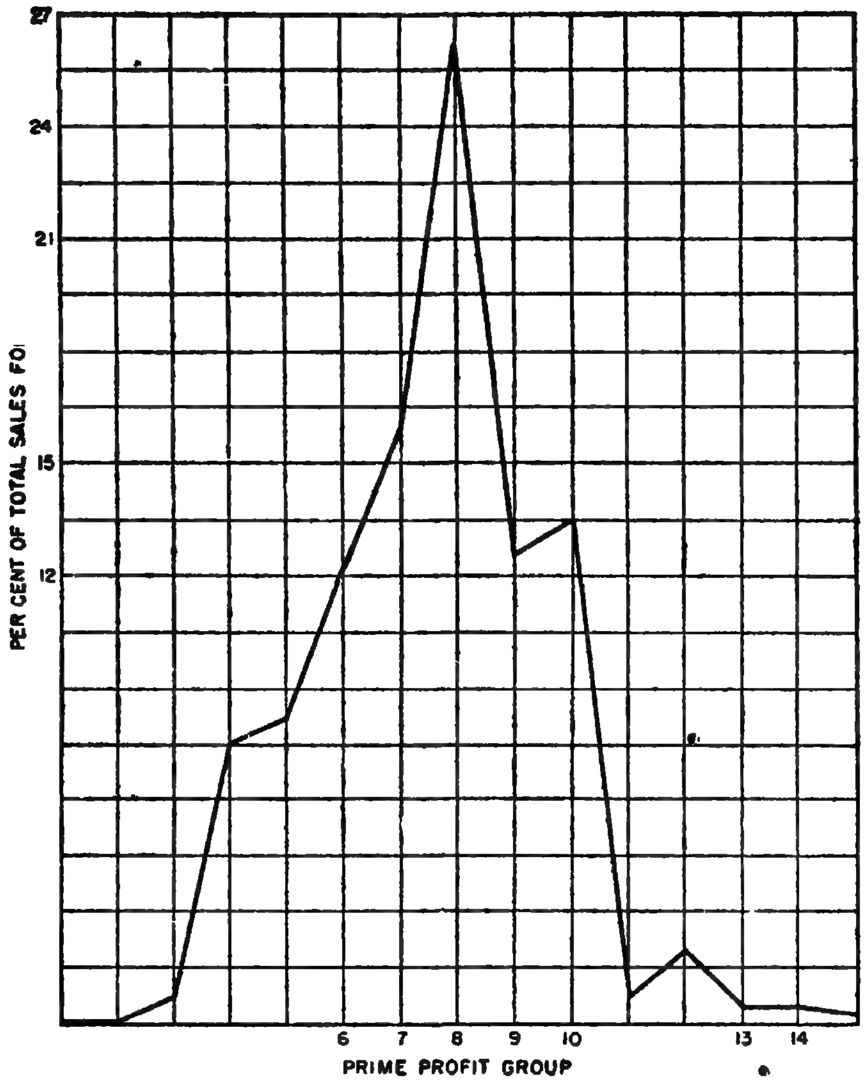


FIG. 16.8 SALES MIXTURE CHART.

retail, and export. A standard selling price was adopted for each product for the purpose of sales control.)

It was decided to classify the items into 15 groups, numbered 1 through 15, according to the direct profit made on each dollar of sales. The sales forecast for each group of items during a given period, expressed in percentage of total sales, is shown in Table 16.3.

These data were plotted as in Fig. 16.8. The groups are in abscissa (represented on the chart by their average direct profit). Their size, expressed in percentage of total sales, is plotted in ordinate. The resulting curve is a sales-mixture chart.

The sales-mixture chart in Fig. 16.8 was then taken as an acceptable standard and served as a basis for actual sales-mixture control. The data related to a given subsequent period will be plotted on the same graph and will result in another curve, which will be compared with the sales forecast curve.

A new curve, more skewed to the left, indicates a higher proportion of less profitable sales. The opposite is true if the new curve is more skewed to the right. If the skewness is approximately unchanged, or if it is a favorable one, no action is taken. If the new sales mixture is unfavorable, management's attention is called to the situation and it may, at its choice, take appropriate action. This does not necessarily imply a reduction of total sales, but rather an attempt to substitute more profitable lines for less profitable ones.

William Gomberg is Director of the Management Engineering Department of the International Ladies' Garment Workers' Union. The Management Engineering Department of the ILGWU furnishes free consulting service to garment manufacturers who have contractual relations with the Union. This Department has become well known as a result of its assistance to management of garments plants in making better use of the plant productive facilities and thereby enabling the workers to increase their output and improve their earnings proportionately. It is also responsible for the policing of piece-rate policies developed by divisions of the Union

Dr. Gomberg pioneered in the development of a department of a union devoted to the field of industrial engineering and both he and the Department have been called upon for consulting work by most of the large national and international unions. He is recognized as the outstanding authority on trade union attitudes and the use of industrial engineering techniques and practices.

Before becoming Director of the Management Engineering Department, Dr. Gomberg worked for the ILGWU as an organizer and as a business agent for one of the large New York locals. He received his B.S. degree from the City College of New York, his M.A. from New York University, and his Ph.D. from Columbia University.

Dr. Gomberg has lectured before a great many professional societies and university classes throughout the country. He is the author of numerous articles in such journals as *Journal of Industrial Engineering*, *Mechanical Engineering*, *Modern Management*, *Harvard Business Review*, *Industrial and Labor Relations Review* and many others. He is the author of *A Trade Union Analysis of Time Study* and *A Labor Union Manual on Job Evaluation*.

Dr. Gomberg served as the union member of the tripartite arbitration panel set up following the strike over a production standards dispute between the Ford Motor Company and the United Automobile Workers in June, 1949. He has also served as a labor consultant to the Economic Cooperation Administration and its successor, the Mutual Security Agency. He is a member of the American Society of Mechanical Engineers, American Statistical Association, Institute of Mathematical Statistics, National Association of Cost Accountants, and the Society for the Advancement of Management.

SECTION 17

Trade Unions and Industrial Engineering

William Gomberg

1. INTRODUCTION

The industrial engineer works at the bridgehead where technological problems merge into social questions. The civil engineer, the electrical engineer, the mechanical engineer have always been applied economists. Their job has been to build a dam, design a dynamo, or fabricate metal shapes to yield a maximum output at a minimum cost.

The industrial engineer's techniques go beyond the mechanical cost factor. He is a designer of organization structures and administrative techniques to achieve specific industrial purposes and is therefore saddled with all the problems attending human relationships. This means that the effective industrial engineer must become apt in the fields of anthropology, sociology, and psychology, among others. Above all, in a democratic society he must understand the relationship between efficiency and consent.

Many of the techniques which the engineer wants to use are frustrated by his inability to secure this consent from the working group. The labor movement today is the principal organized force through which the engineer speaks to and negotiates with workers. For example, the industrial engineer wants to raise productivity. Who can be against increased productivity? It's like being against the Ten Commandments. He asks the trade unionist, "You're in favor of increased production aren't you?" Then the industrial engineer goes to work. He pulls out a stop watch and is all but physically thrown out of the

plant. He proposes a job evaluation system and is laughed at. He demonstrates with movies, if you please, that it is easier to move a piece of metal ten inches than ten feet, and still the worker insists upon his old ten-feet method.

Yes, the other engineers may have their problems, but nothing like this. If the civil engineer wants to understand what it's like to be an industrial engineer, let him visualize a dark, eerie Halloween night on which spirits, animate and inanimate, are abroad. Along comes the bridge, which is his pride and joy, spanning a majestic river. It addresses him in these words: "Hey, do you know that I could have remained standing and carried just as big a load if you had used one quarter the tonnage of steel that my poor piles must hold up?"

This is just an everyday experience for the industrial engineer. The appearance of the trade union in the picture merely gives open, organized expression to this feeling. It at least means that the engineer can deal with this problem through an organized group.

It is, of course, important that the engineer know what the attitude of the labor movement is toward any of the techniques he wants to install, but it is even more important that he understand the reasoning behind the union's attitude. The logic behind the labor movement's attitude toward time study, job evaluation, wage incentive payment plans, and so forth, is best understood against an examination of the nature of the trade union institution itself. How does the union think? How does its system of values, from which much of its thinking stems, differ from the customary reasoning of management?

2. ATTITUDES AND IDEOLOGIES OF ORGANIZED LABOR

An attempt will be made to examine the basic thinking behind the trade union, the development and evolution of this thinking, and the parallel history of the scientific management movement and the trade unions as they interacted on each other. We shall then proceed to an analysis of the growth of a trade union philosophy of industrial engineering. We shall examine specific areas of industrial engineering such as time study, wage incentive payment plans, and job evaluation techniques. We shall trace different trade union attitudes, making use of cases before the National Labor Relations Board and private voluntary arbitrators. Finally, we shall examine the related and relatively new fields of industrial psychology, including aptitude testing and human relations techniques, to determine what trade union reactions can be expected in that area.

Sidney and Beatrice Webb are the recognized historians of Western trade unionism here and abroad. They trace the pressure for trade unionism to the divorce of the worker from the tools which he requires to do his work. Unions arose, they tell us when

> . . . the great bulk of the workers had ceased to be independent producers, themselves controlling the processes and owning the materials and product of their labor, and had passed into the condition of lifelong wage earners, possessing neither the instruments of production nor the commodity in its finished state.*

Contrary to most general notions, trade unionism did not arise as a great revolt of a miserably paid, unskilled proletariat. Philip Taft says, "It was not the worker who had the lowest bargaining power but the one with the greatest sense of independence who pioneered the trade union movement." †

This development was inevitable, for only the worker with the greatest sense

* We are indebted to the Trustees of the late Lord Passfield for permission to reproduce an extract from *History of Trade Unionism* by Sidney and Beatrice Webb, published by Messrs. Longmans, Green & Co. Ltd.

† Philip Taft, "Theory of the Labor Movement," in *Interpreting the Labor Movement* (Industrial Relations Research Association, December 1952), 5.

of independence was willing to challenge the authority of the employer in the early days of organization, and it required some threat to existing customs and standards to initiate organization. Therefore, it was not the propertyless proletariat of Marx, but the labor aristocrat who was the pioneer of trade unionism.

This concept of the initial organization of trade unions is of great importance in understanding current labor movement behavior. It provides the rock upon which so many ideological pretensions, served up by both friendly intellectuals and ambitious labor leaders, have foundered.

Defining the objectives of the labor movement has been undertaken by social scientists, ideologists, and the labor leaders themselves. To begin with, the term "labor movement" is a much broader classification than the term "trade union." Trade union activities themselves are generally confined to activities which bear immediately upon questions of wages, hours, working conditions, and the direct-pressure techniques such as strikes to secure these objectives. Labor movement activities include a much broader area, extending to such matters as politics, civic activities, and problems relating to the general welfare. The priority that any of these activities takes is not always reflected in the correlative amount of publicity that each of these activities receives. The general public is, therefore, likely to be confused about the central purpose of the trade union. This confusion was compounded by revolutionary ideologists who had hoped to use the trade unions as levers to overthrow existing social relationships and to remake society into a new utopian image.

The fact of the matter is that the first classification of unions undertaken by Hoxie attempted to list them in accordance with the ideological pattern professed by their different current leaders.*

* R. F. Hoxie, *Scientific Management and Labor* (New York: D. Appleton & Co., 1915).

Hoxie's successors have revised his original listings somewhat, but to this day the rather vague phrase of conservative unionism vs. progressive unionism remains in common usage.

Conservative unions are loosely identified as business unions that profess no particular long-run objectives. They are supposed to be opposed to the use of the strike weapon, to emphasize craft jurisdictions, and continually to be embroiled in jurisdictional disputes. They are supposed to eschew political interest and to confine their solidarity and interest to their own immediate membership.

Progressive unions are likely to profess political attitudes varying from an enthusiasm for specific New Deal measures to a complete reorganization of society into a democratic cooperative commonwealth. They tend to emphasize the industrial form of organization. Their emphasis on working-class solidarity is supposed to keep them clear of all jurisdictional contests.

Yet when we analyze the day-to-day activities of both types of unions, we are struck by their similarities rather than by their differences. Strangely enough, both the unions that started with radical or socialist aspirations and those that either did not question the social order or even expressed positive loyalty to private enterprise found that they were doing essentially the same thing. The philosophy pursued by unions in their actions, irrespective of any ideological professions, was first formulated by Professor Selig Perlman of the University of Wisconsin, whose theory of job-conscious unionism built the whole dynamics of the labor movement around the job.

Professor Perlman has pointed out that unions base themselves on a consciousness of limited job opportunities —a situation which requires that the individual worker, both in his own interest and in the interest of the group to which he belongs, occupy his job on the condition that he observe the common rules formulated for the group by his union. The union in turn seeks by collective bargaining with the employer

to establish rights in the jobs for both the individual and the whole group.*

The bankruptcy of these old ideological divisions becomes apparent when we examine the actual trade unions. An old conservative trade union like the A.F. of L. Teamsters Union has extended its jurisdiction to warehouses, so that to all intents and purposes it has become an industrial union.

On the other hand, the CIO United Auto Workers Union has been compelled to modify its industrial structure to give recognition to craft problems. For example, it has created a special tool and die council charged with taking up the problems of highly skilled workers.

The preoccupation of trade union leadership with the day-to-day problems of unions, irrespective of the political and ideological conviction professed by any of them, soon places any utopian panaceas in the background. Negotiating contracts, administering agreements, handling grievances become the full-time job of the trade unionist. Political activity in which trade unionists do engage is strictly subordinated to these considerations.

This preoccupation has been the bane of many an ambitious intellectual. When a union is attempting to establish itself in its early developmental stages, it attracts a wide variety of people. Some of them are dedicated idealists who look upon the trade union movement as a lever that will enable them to reconstruct society along models which they have developed out of either a Marxist philosophy or some other revolutionary philosophy. Others who are attracted are either conscious or unconscious agents of the Soviet foreign office, and, as members of the Communist Party, seek influence in the organization to shape it to the Party's needs. These needs may vary from very close collaboration with employers to raise production to pointless strikes designed to wreck the economy. A communist-led union is not a left-wing union. It is an American institution captured by the agents of a foreign power to serve the needs of that foreign power in very much the same manner that the pre-war management of many foreign corporations were institutions designed to serve the needs of the Nazi foreign office.

Sooner or later, a conflict develops between the elements in the union who are attempting to serve the economic needs of the workers and those who are dedicated to the use of the organization to promote the needs of their new model society. Very often, the very leaders who may have come to power because they were driven by the idealistic vision of the new society they were going to create find that they are the victims of a new schizophrenia. They must choose between the immediate economic needs of their members and the long-term requirements of their vision. The United States' democratic atmosphere, which has always been pragmatically anti-ideological, compels them, if they are to remain as trade union leaders, to seek the satisfaction of short-run economic ends.

The history of the last few years is replete with examples of progressive trade unionists who began as heroes of the *Daily Worker* only to be later denounced as arch villains. Others have been pilloried by anti-Stalinist intellectuals for not making their trade union the springboard of power policies which would reshape society nearer to their heart's desire.

The manner in which a wedge is driven between the trade unionists and the ideologists is perhaps best illustrated by two examples. Some trade unionists had made it a habit to endorse some of the many communist "fronts," such as the communist-controlled Civil Rights Congress. Attacks upon them were ignored by these trade unionists. Many of the people who had attacked them they recognized as people whom they had bitterly fought to organize their union in the first place. Sending delegates to a Civil Rights Congress didn't particularly interest them and didn't

* S. Perlman, *A Theory of the Labor Movement* (New York: Augustus M. Kelley, 1949).

interfere with any critical economic problems which they had to face. On the other hand, when the Communist Party attempted to mobilize them to call irresponsible strikes or to protest the Marshall Plan, many of these unionists who had been pliable communist allies before told the communists to go to hell. Calling a non-economic strike merely to contribute to chaos in the United States might serve the purposes of the Communist Party, but it would wreck the trade union which the leader heads. Denouncing the Marshall Plan might again serve the needs of the Soviet foreign office, but the inauguration of the Marshall Plan meant employment for many trade unionists in export industries. Confronted with this dilemma, the trade unionist who was either friendly or indifferent to the communist had to become actively hostile.

The Socialist Party encountered a very similar experience though for an altogether different set of reasons. Building a socialist force in the United States called for the election of socialist candidates. On the other hand, preserving the collective-bargaining position of American unions called for the election of New Dealers. Again in the choice between ideological allegiance and the collective-bargaining needs of the union, the collective-bargaining needs took precedence.

Neither the Marxist economist nor the classical economist has much patience with everyday, undramatic trade unionism. The classical economist finds the union interference with the normal competitive forces governing wages and hours an unbearable assault upon his carefully nurtured escape from reality called "a picture of our economy." The Marxist finds the trade union a barrier to his leadership of the working masses, whom history has predestined as the vehicle that will carry him to political power. The trade unionist in turn exclaims a pox on both their houses and continues to pursue his aims. They are:

1. To provide a means for the democratic settling of wage rates and working conditions.

2. To replace the little oriental despotisms that formerly made up our business world with democracies governed by a code of juridical law.

Perhaps Tannenbaum has put it best when he says, "The trade union movement has survived because it satisfies the workers' craving for moral status in a recognizable society." *

The most important conclusion that an industrial engineer can draw from this picture of the labor movement is that the reaction of any particular organization to a proposal for an engineering installation will depend much more on the economic and industrial problems as they reveal themselves in collective bargaining than on either the ideological professions of the union leadership or the resolutions that are extracted from convention proceedings. For example, the constitution of the International Association of Machinists, A.F. of L., prohibits the recognition or promotion of incentive wage payment plans. Yet collective-bargaining realities have compelled the leadership of the I.A.M. to maintain specialists in these fields on their headquarters staff to cope with these problems as they arise. This is a good example of the cultural lag between the ceremonial expressions of the labor movement and its actual operating behavior dictated by common-sense pragmatism.

Present practices can best be understood, however, against the background of the concurrent development of the American labor movement and the scientific management movement. The evolution of the trade union movement's attitude toward productivity and the impact of the collective bargaining process on productivity itself reveal a uniquely American phenomenon which has made the United States the most productive country in the world.

* Reprinted from *A Philosophy of Labor* by Frank Tannenbaum, by permission of the publisher, Alfred A. Knopf, Inc. Copyright 1950, 1951 by Alfred A. Knopf, Inc., p. 13.

3. THE INTRODUCTION OF SCIENTIFIC MANAGEMENT

Taylor's publication in 1895 of his paper, *A Differential Piece Rate,* can be taken as the starting point of the scientific management movement. This was just nine years after Samuel Gompers had called the founding convention of the American Federation of Labor.

McKelvey has divided the history of the relationship between the scientific management movement and the labor movement into these distinct periods to which I have added a fourth.

1. A period of unmitigated hostility between scientific management and organized labor, lasting from 1911 to 1915.
2. A period of transition, extending from 1915 to 1917.
3. A period of friendliness and understanding between the two movements, up to the great depression.
4. The emergence of a positive trade union philosophy of industrial engineering following the great organization drives and with the passage of the New Deal legislation.*

The remainder of this section will treat the development of the first three periods.

Taylor's philosophy of scientific management left no room in the scheme of things for trade unionism. Actually underpinning Taylor's philosophy was a doctrine of rugged individualism which left no room for any teamwork concept. Every worker was pitted against every other worker in a wild competitive scheme to make more and earn more. When Taylor illustrated his philosophy with examples like those of the pig-iron handlers who in return for an increase in output on a hand-paced operation of 400 per cent were rewarded with a 40 per cent increase in wages, the fury of the trade unionists waxed hot. The issue was formally joined when the government introduced the Taylor Premium Pay Plan at the Watertown Arsenal in Massachusetts in 1909. The unionized molders struck and were immediately supported by the American Federation of Labor. Gompers wrote vitriolically in the *American Federationist:*

> Systematization in getting materials ready for the ultimate workman on the final job is not novel but scientifically building up the skilled mechanic himself . . . molding, hammering, filing and polishing him off in order to fit him for his theoretically best usefulness—that charms us unto the very soul.*

But Taylor insisted:

> An establishment running under the principles of scientific management will confer far greater blessings upon the working people than could be brought about by any form of collective bargaining.†

Taylor insisted that the distribution of the product among labor, the consumer, and the public could be done on an objective scientific basis. This confusion of scientific concepts with value judgment was behind much of the antagonism that Taylor generated among trade unionists. The promotion of scientific management systems to managers as substitutes for trade unions made this a matter of life and death with the unions.

In 1910, Louis D. Brandeis, later a Supreme Court Justice, introduced the testimony of one of the leaders of the scientific management movement, Harrington Emerson, into a case before the Interstate Commerce Commission. Mr. Brandeis was appearing on behalf of a group of shippers who were protesting the application of the railroads for an increase in freight rates. Mr. Emerson testified that the railroads could save themselves $1,000,000 per day by the adoption of scientific management techniques. This made the conflict between the scientific management movement

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* J. T. McKelvey, *AFL Attitudes Toward Production, 1900-1932* (Ithaca: Cornell Studies in Industrial & Labor Relations, Vol. II, 1952).

* *Ibid.*, p. 16.

† Reprinted by permission from *Frederick W. Taylor* by F. B. Copley, Vol. II (New York: Harper and Brothers, 1923), p. 416

and the labor movement front-page news and led to a number of government investigations. The proceedings before these public bodies gave both sides an opportunity to spell out the issues and their respective positions.

The first of these bodies was an investigating committee of the House of Representatives. The purpose of the committee was to determine whether or not the techniques of scientific management should be permitted in government arsenals and navy yards.

The following exchange before the committee points up the conflict between the exponents of scientific management and the leaders of organized labor.

> The Chairman: The other day Mr. Taylor, you made the statement that the mechanism of scientific management was a power for good and a power for bad.
>
> Mr. Taylor: Yes, sir.
>
> The Chairman: Now, if scientific management is a power for good and a power for bad and scientific management requires that there shall be only one directing head, with no interference with the law of that directing head, how is the workman going to protect himself against the power for bad that is in that system?
>
> Mr. Taylor: Why, that is not scientific management, Mr. Chairman. I have tried to point out that the old fashioned dictator does not exist under scientific management. The man at the head of the business . . . is governed by rules and laws. . . .
>
> The Chairman: If the enforcement of a law, however, is dependent upon the will of a man who has the power to violate it, there is not much likelihood of the law being enforced against him is there? *

Organized labor could not have expressed its view any more clearly than this government representative. Some four years later, however, a rider was attached to a naval appropriations bill prohibiting the use of government funds for stop-watch studies in government plants.

In 1914, the United States Commission on Industrial Relations undertook still another investigation of scientific management as one phase of its total investigation of United States industrial relations. When Carl Barth, a leading associate of Taylor's, was called to the stand, the following exchange took place between him and the chairman.

> Mr. Thompson: Then you have not taken into consideration the question of collective bargaining?
>
> Mr. Barth: No; not very seriously, because I do not shake hands with the devil.*

Attitudes like this were hardly designed to endear the scientific management movement to the labor unions.

Professor Robert R. Hoxie of the University of Chicago was requested by the Commission on Industrial Relations to undertake an investigation of whether or not there were any possibilities of reconciling the scientific management movement with the organized labor unions. Professor Hoxie was joined by John P. Frey, editor of the A.F. of L. *Molders Journal*, and Robert G. Valentine, a management counselor.

The labor movement objections to scientific management that were examined by the investigators may be divided into two categories: conflicts over techniques involving pure difference in measurement, and conflicts implied in different interpretations of just how our economy works. Among the measurement objections may be listed the following:

> It [scientific management] looks upon the worker as a mere instrument of production. . . .
>
> [It] stimulates and drives the workers up to the limit of nervous and physical exhaustion. . . .
>
> [It] holds that if the task can be performed it is not too great. . . .

* Reprinted by permission from *Scientific Management* by F. W. Taylor (New York: Harper and Brothers, 1911), p. 188-189.

* McKelvey, *AFL Attitudes Toward Production, 1900-1932*, p. 19.

It tends to set the task on the basis of stunt records of the strongest and swiftest workers without due allowance for the human element or unavoidable delays. . . .

It ordinarily allows the workman no voice in . . . the setting of the task . . . or the general conditions of employment. . . .*

Note that every one of these objections is a measurement objection—that is, a rejection of the management method of measuring a task.

Now follow another set of objections based upon a conflict in ideas about the automatic distribution of the fruits of high productivity.

It leads to overproduction and the increase of unemployment. It puts into the hands of employers at large an immense mass of information and methods which may be used unscrupulously to the detriment of the workers . . . and offers no guarantee against the abuse of its professed principles and practices. . . .

It forces the workers to depend upon the employers' conception of fairness and limits the democratic safeguards of the workers. . . .

Finally,

It concerns itself almost wholly with the problems of production, disregarding, in general, the vital problem of distribution. . . . [It] violates and indefinitely postpones the application of the fundamental principle of justice to distribution.†

If the Hoxie Commission did not bring about a reconciliation between the scientific management movement and the trade unions, it did at least clearly spell out the issues. The Hoxie Report can be said to close the first period of unmitigated antagonism between organized labor and the scientific management movement.

A dissident group, however, within the scientific management movement had begun to express itself somewhat earlier than the Hoxie Report.

The groundwork for a transition to a more viable relationship between these two currents of thought was being laid by men like Henry Gantt, Robert G. Valentine, Morris Cooke, and Louis D., later Justice, Brandeis. Brandeis had declared in his original brief, submitted in 1910 in the Eastern States Railroad Rate Hearing, that

Collective bargaining is alike an important function under scientific management and under the old system.

The following exchange between Brandeis and Gantt took place at the hearing. Gantt was an expert witness.

Mr. Brandeis: But it is, as Commissioner Clark has pointed out, perfectly possible, and indeed very probable that there would always be two sides to the bargain?

Mr. Gantt: Yes, sir.

Mr. Brandeis: Because you would have to fix the terms where the bonus would begin, and the amount of the bonus, and therefore collective bargaining in the sense of having a union to represent the working men, would . . . be just as necessary and just as beneficial in its operation as it is today.*

Henry Gantt had shown some suspicion that the mere institution of scientific management would not necessarily lead to unlimited production. As early as 1910, he had observed that the administrators of some of these techniques seemed to be more interested in making prices than they were in making products.†

It was in 1915, however, that Robert G. Valentine published his classic paper *The Progressive Relationship between Efficiency and Consent*. He stated:

Under constitutional industrial relations, they [the unions] will contest the share in the management and the share of the product between themselves and the consumer.

* Hoxie, *Scientific Management and Labor*, p. 169.

† *Ibid.*, pp. 170–173.

* L. D. Brandeis, "Scientific Management," *Engineering Magazine*, 1911, 55.

† H. Gantt, "Work, Wages and Profits," *Engineering Magazine*, 1911, 231.

Separating the problems of scientific management into two categories, he called the Taylor Society to provide a planning department to treat two classes of problems:

1. Those relating to the determination of the best way of performing an operation under a given set of conditions.
2. Those relating to the social, industrial and moral effects of putting into operation the organization or methods which scientific investigation has determined to be technically the best.

Finally, he defined the relationship between efficiency and consent—the doctrine that the worker individually and in organized groups has a right to share in the determination of the conditions under which new technical methods and apparatus shall be put to use.

Shortly thereafter, Valentine and Brandeis received an opportunity to apply their techniques experimentally amid a good deal of hope and optimism.

In January, 1916, a board of arbitration, of which Louis D. Brandeis was a member, handed down an award revising "A protocol of peace governing the relationship between the Dress and Waistmakers Association of New York City and the International Ladies' Garment Workers' Union." The award provided for a board of protocol standards charged among other duties with supervising the making and testing of piece rates and the assignment of standard times to different operations in the garment industry. Robert G. Valentine was chosen as the first chairman of this board. The board was set up in March, 1916, but by September disagreements and rejection of its finding by the employers' association had led to complete ineffectiveness. By 1917, we were in World War I; Valentine had died and a new era in the importance of organized labor in federal affairs had begun.*

World War I opened up new opportunities to leaders of the labor movement. President Wilson instructed the Secretary of Labor to set up a federal board of arbitration. The Secretary of Labor set up a war labor conference board on which there was an equal number of representatives from the National Industrial Conference Board and the American Federation of Labor. The conference suggested the organization of a National War Labor Board. The new agency was governed by the following principles:

1. The right of workers to organize in trade unions and to bargain collectively through chosen representatives is recognized and affirmed.
2. Employers should not discharge workers for membership in trade unions nor for legitimate trade union activities.*

These measures lent labor a degree of security. Finally, when Samuel Gompers himself was chosen a member of the advisory commission of the Council of National Defense, it meant that the scope of his activities reached outside the immediate employer-employee relationship. Other labor leaders were called upon to serve on various policy-setting boards. In addition, a friendship developed between Morris L. Cooke and Samuel Gompers. Cooke was one of Taylor's original associates and was prominent in the affairs of the Taylor Society and the American Society of Mechanical Engineers. It was this social contact that led to the reconciliation between the leaders of the scientific management movement and the organized labor movement. The experience that organized labor had developed in its participation in joint labor management committees led the movement to look forward to a constructive relationship between itself and management following World War I. The regular stream of management took its leadership from Elbert Gary of United States Steel. Strangely enough, the group around the Taylor Society became a sort of left-wing management group which continued to develop an experi-

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* L. Levine, *The Women's Garment Workers* (New York: Huebsch, Inc., 1924), pp. 306-309.

* McKelvey, *AFL Attitudes Toward Production, 1900-1932,* p. 33.

mental approach to the theory of organization and administration of industrial enterprises and labor participation in these functions.

In 1919, the year following the end of the war, two developments took place. First, President Wilson called an industrial conference to enable labor and management to set out a policy that would promote production and preserve industrial peace. Second, Samuel Gompers agreed to edit jointly with Morris L. Cooke and Fred Miller, President of the American Society of Mechanical Engineers, a set of papers expressing the points of view of the industrial scientists and the representatives of organized labor. This volume was published by the American Academy of Political and Social Science.

The contrast in approach and treatment of the problem by the management participating in the President's Conference on Industrial Relations and the group editing the *Annals of the American Academy of Political and Social Science* is perhaps best indicated by the material published by each of the groups.

The President's Industrial Conference broke up when management insisted upon the following resolution:

> Resolved: that without in any way limiting the rights of wage earners to refrain from joining any association or to deal directly with the employer as he chooses, the right of the wage earners . . . to bargain collectively with employers is recognized. The right of the employer to deal or not to deal with groups of men who are not his employees is recognized.*

By way of contrast, in the volume, "Labor Management and Production," the engineers stressed the importance of giving labor a voice not only in collective bargaining but in industrial management itself.†

The overwhelming majority of management representatives took their cue from the Industrial Relations Conference statement. A great union-busting campaign was undertaken which reduced the importance of the unions to a shadow of their World War I strength.

The publication of *Waste in Industry* in 1921 marked another milestone in bridging the gap between organized labor and the leadership of the scientific management movement. This volume was the outcome of a proposal made by Herbert Hoover to the Council of the Federated American Engineering Societies that a group of engineers conduct an organized survey of a number of chosen industries and make recommendations for the elimination of wasteful practices. The committee assayed the wastes in industry and made recommendations calling for the participation of labor in administrative decisions that would eliminate waste. In other words, instead of merely philosophizing about labor's participation in industry, it pioneered a blueprint for such participation.*

The leaders of organized labor protested in vain their new-found interest in production. As late as 1925, labor still proclaimed:

> There is still a more important service that the union can render, that of participating in finding better methods of production and greater production economies. A group of workers cannot enter into this type of cooperation unless they know the results of their work will not be used to their disadvantage.
>
> We recommend that the Federation keep in touch with such engineers and industrial experts as may be helpful in developing the information and procedure necessary to union management cooperation.†

Gompers was invited to make speeches to the American Society of Mechanical Engineers, and Green, his successor, to

* *The New York Times*, October 17, 1919, p. 1.

† "Labor Management and Production," *Annals of the American Academy of Political and Social Science* (1920), pp. viii-ix.

* McKelvey, *AFL Attitudes Toward Production, 1900-1932*, p. 69.

† *1925 Report of the Executive Council of the American Federation of Labor Convention*, p. 32.

the Taylor Society. A number of interesting experiments emerged out of this cooperation between management's left wing and the American labor movement, but by and large the twenties was an "ice age" for labor with an occasional warm island known as an experiment in union-management cooperation.

Under the influence of men like Morris L. Cooke, Otto Beyer, and Geoffrey Brown, several joint experiments were taken up in the twenties. The Cleveland agreement between the International Ladies' Garment Workers' Union and the Cleveland Manufacturers Association, the Baltimore and Ohio experiment, and the Naumkeag experiment were the most heavily publicized of these ventures.

The agreement between the Cleveland Manufacturers Association and the International Ladies' Garment Workers' Union called for the setting of piece rates by time study techniques.

Under the Baltimore and Ohio experiment, committees of workers were set up independent of grievance committees to make operating suggestions in the maintenance shops of the railroads.

The agreement between the United Textile Workers Union of America and the Naumkeag textile mills in New England likewise called for the use of time study techniques to increase work loads.

The experiences which these unions accumulated with the technique were later to give rise to the positive development of a trade union philosophy of industrial engineering. The common denominator shared by these experiments was that the unions frankly acknowledged an interest in increasing production, and administrative machinery was set up in each case to help the parties carry through their objectives.

Each of the experiments had terminated by 1931, when the great depression made any concern with productivity by either management or labor appear completely obsolete. The course of the experiment during its successful phase left very little impression on American industry, although it did cause some commotion in the intellectual world. At the time of the demise of the experiments, the fundamental industrial relations policies of large American mass-production corporations remained anti-union, and it was they rather than the intellectual who dictated the business environment.

It is difficult to draw a fine line between the area where ordinary collective bargaining ceases and union-management cooperation begins. Collective bargaining itself starts with a pure conflict psychology and then, in a developing relationship, the conflict is attenuated and a new relationship develops out of the old. For example, John Mitchell, President of the United Mine Workers of America, in 1890 defined trade agreements as ". . . treaties of peace determining the conditions under which the industry will be carried on." Note that the whole emphasis is on conflict, either active or suspended.

Ordinary collective bargaining begins to evolve into union-management cooperation—or into an invasion of management prerogatives, depending upon your set of prejudices—when the union is ready to discuss subjects like production and sales outside the immediate employer-employee relationship. All through the twenties the American Federation of Labor emphasized its devotion to the concept of union-management cooperation. It frankly was using cooperation in good faith as an organizing technique. The southern organizing drive of the twenties made its appeal to employers by offering the services of the Federation to reduce wastes and increase work loads by setting up committees to give workers a democratic voice in decisions affecting them. President Green undertook a speaking campaign in the South in which he publicized the doctrine. He said:

> We offer to management and to the owners of industry a cooperative organization willing to give the best we have in training and service and skill in order that the industry may be made profitable.

Geoffrey Brown, an industrial engineer, served on the Federation's staff

and held innumerable conferences with southern textile manufacturers. He wrote to one of them:

> I would like to emphasize to you again that the union-management co-operation plan that I am prepared to develop is constructive in character and is designed to place the working force four squarely behind production in such a way that a high hourly output per worker and a minimum unit labor cost will be maintained uniformly throughout the mills. The plan contemplates the organization of a joint co-operative committee to confer on such matters as . . . scientific extension of the number of looms or spindles . . . per operator . . . and any other matter in which the effectiveness of the worker influences the prosperity of the mill.*

The campaign won almost no buyers and the Federation, along with the rest of the labor movement, turned toward more classical organization techniques when the passage of the National Industrial Recovery Act in 1934 made the organization of workers once more feasible. These experiences with union-management cooperation influenced very deeply the attitudes of the growing trade unions toward productivity as a concept and toward industrial engineering techniques as tools of collective bargaining.

It is already obvious from what has been said that the concept of union-management cooperation did not carry enough appeal to sell unionism to employers except in some very exceptional cases. Both the Naumkeag experiment and the Cleveland Garment Workers' experiment broke down because the depression made it impossible for workers threatened with unemployment to see any particular advantage in participating in high-productivity schemes. The railroad experiments continued on a much reduced plane and with a declining enthusiasm, for the same reasons.

The new unions, which were growing rapidly, and the old unions, which were increasing their membership at a very rapid rate, were formulating, by their activities, their own philosophy of production. The writer once attempted to outline at a public forum this attitude, which, though it may not have ever received formal expression, nevertheless portrays the thinking of the trade unionist on the subject of productivity.

> The question of productivity is posed more as a challenge than as a search for dispassionate information. The challenge generally proceeds on the implicit assumption that, by and large, management is for high productivity, and that, by and large, labor is for restricted productivity. The role of a few progressive unions is acknowledged. This is supposed to point up the contrast with what is considered the more common restrictionist behavior.
>
> The truth is that both management and labor view this question of high productivity from different angles. Management is interested in the intensive view of high productivity. Labor, on the other hand, is interested in the extensive view of high productivity.
>
> When management says they want high production, they mean that they want the highest production that they can possibly get during those hours when they find it profitable to permit the workers to operate the machines of which they are the custodians. Should they find it unprofitable to operate these machines, then they would be considered very unwise managers indeed if they went on turning out merchandise classed in accounting language as idle inventory. In fact the efficiency of the manager will be judged in terms of whether or not he is wise enough to shut down his factory in time to avoid accumulating an idle inventory. This behavior is considered sound business practice and is socially acceptable. Actually, it is a wanton waste of our irreplaceable manpower resources.
>
> Now take a working man. He's been conditioned by his historical fear of unemployment. He finds through the factory grapevine that, at most, six weeks of work is left in the factory. His problem is: what do you do at the end of six weeks? Well, it would be a lot easier if you didn't have to face the problem for seven weeks. And so he will resort to devices to make six weeks' work last seven weeks. Immediately

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* McKelvey, *AFL Attitudes Toward Production, 1900-1932*, pp. 105-106.

aimed at his head is the accusing finger labeling him "featherbedder" and "victim of the make-work fallacy." He's interested in high production, but he calls it full employment.

This is what I mean by the contrast between the worker's interest in the extensive view of high productivity and management's interest in the intensive view of high productivity.

Obviously both management and labor are reacting normally to the logic of their experience. Hortatory harangues about the necessity for high production in the abstract just bore everybody.

. . .

> The union institution must resolve two contradictory forces which the members press upon the leadership. Your membership wants at the same time a defensive safeguard against technological innovation and simultaneously some of the gains that come from that same innovation. Obviously, in an expanding economy the union can emphasize the gains available. It is not afraid of unemployment.*

This last paragraph, of course, is the key to the union's behavior in a local situation. Joe Scanlon and Clinton Golden, formerly Research Director and Assistant to the President of the Steel Workers Union and more recently members of the faculties of the Massachusetts Institute of Technology and Harvard University respectively, have had dramatic success with some union-management cooperation plans for which both have been responsible.

A careful analysis of the application of the Scanlon Plan in the La Pointe factories and the Stromberg-Carlson factories discloses nothing very unique except the development of a new human relationship between the management and the workers under the leadership of a very forceful personality like Joe Scanlon. What made it possible, however, for Mr. Scanlon to exert this influence on the principals was the expanding economy of the country in 1950. The workers' fear of unemployment was at a minimum and Mr. Scanlon's persuasiveness led the management to permit the union to participate in a whole host of activities that would be listed elsewhere as management prerogatives. The particular group incentive payment plan in which workers augment their wages by attempting to raise productivity by reducing actual costs below a standard cost has been used elsewhere with mixed results. It would therefore be a mistake to confuse the mechanics of the Scanlon Plan of union-management cooperation with the effective ingredient which is Mr. Scanlon's personality.

Most of the so-called War Production Committees—or Nelson Committees, as they were called, after Donald R. Nelson, Chairman of the War Production Board—never really functioned despite the plethora of publicity that they were accorded. This was because management looked upon these committees with suspicion, for two reasons:

1. They would increase the power of the unions.
2. They permitted the unions to invade areas of management which were still the subjects of controversy. Management maintained, for example, that the application of many industrial engineering techniques remained a unilateral function of management.

It is thus interesting for the trade unionist to watch the ambivalence of management behavior. First, management deplores the union's lack of interest in subjects like high productivity and its attendant techniques, such as accounting, time study, and rate setting. When the union is ready to discuss these subjects in collective bargaining, it is likely to be accused of invading management prerogatives.

The principal problem faced by trade unionists in coping with management techniques was first to gain recognition that the techniques of the industrial engineer belonged in the area of collective bargaining. In the course of developing this case, an entire philosophy of trade union industrial engineering was developed.

* W. Gomberg, "Release the Brakes on Output," *New York Herald Tribune* Forum, October 1950.

The different areas covered by collective bargaining continued to be a matter of serious dispute immediately following World War II. President Truman called a conference made up of the national leadership of the national employers' associations and the national labor federations, the American Federation of Labor, the Congress of Industrial Organizations, the Railway Brotherhoods and, finally, the United Mine Workers of America. Among the subcommittees appointed by the conference was the subcommittee on "Management's right to manage." This subcommittee was made up of an equal number of representatives of management and labor. Since the subcommittee was unable to come out with a joint report, two separate reports were issued—one by management and the other by labor.

The management members addressed a letter to the conference, extracts from which follow:

> Labor members of the committee on Management's Right to Manage have been unwilling to agree on any listing of specific management functions: . . . if labor disputes are to be minimized by the genuine acceptance by organized labor of the functions and responsibilities of management to direct the operation of an enterprise, labor must agree that certain specific functions and responsibilities of management are not subject to collective bargaining.

The committee then went on to list some of the duties which they felt were outside the jurisdiction of collective bargaining:

> . . . The location of the business, including the establishment of new units and the relocation or closing of old units. . . .
>
> . . . The determination of job content; the determination of the size of the work force; the allocation and assignment of work to workers.

The labor group on the other hand pointed out that:

> The extensive exploratory discussions of the committee have brought forth the wide variety of traditions, customs and practices that have grown out of relationships between unions and management in various industries over a long period of time.
>
> It would be extremely unwise to build a fence around the rights and responsibilities of management on the one hand and unions on the other. The experience of many years shows that with the growth of mutual understanding the responsibilities of one of the parties today may well become the joint responsibility of both parties tomorrow.*

Labor was in short accusing management of committing the logical fallacy of "false concreteness," a favorite fallacy of the legal-minded who must fit all living phenomena into a system of verbal categories. It was in this environment that the labor movement philosophy of industrial engineering developed.

We now proceed to an examination of the individual engineering techniques and the development of a collective bargaining treatment of these techniques. The techniques that will be examined are:

1. The development of job analysis and job evaluation systems.
2. The development and installation of work simplification schemes.
3. The development and administration of production standard-setting techniques.
4. The development and administration of wage incentive payment plans.

4. JOB ANALYSIS AND JOB EVALUATION

Trade unionists have disagreed sharply over the usefulness of job evaluation as a collective bargaining tool. The pedigree of the technique itself would have led to initial prejudice.

What appears to have been the first formal job evaluation plan was proposed by Merril Lott in 1925 in the magazine, *Management and Administration.* Later, Mr. Lott's ideas were incorporated into

* *President's National Labor-Management Conference,* November 5-30, 1945, U. S. Department of Labor, 1946, pp. 56-61.

a book published by Ronald Press. Somewhat later, Mr. A. L. Kress developed the National Electrical Manufacturers Association Plan on a similar point basis. It was later taken over by the National Metal Trades Association and became its official plan. At about the same time, the factor comparison method of job evaluation was developed in the Philadelphia transit properties of the Mitten interests.

Since that time almost all plans, and there seem to be as many as there are people installing them, have followed along the initial pattern laid down by these original designs.

It is important to remember that both the National Metal Trades Association and the Mitten interests were anti-union in the twenties. In fact, the unions felt that the NMTA looked upon job evaluation at that time as merely another equity device that would keep unions out of the plants of its members. The development of these techniques, under such auspices, hardly accorded their use a sympathetic hearing by trade unionists, regardless of their technical merits or usefulness. Later, however, the users of these techniques hastened to explain that they were anxious to fit their use into the collective bargaining framework.

The entire subject was distasteful to some trade unionists for another reason. For example:

> President Harvey Brown of the Machinists tells of a situation in a midwestern metal working plant "organized by the Machinists and other crafts." Management installed a job evaluation system which in one department had the effect of substituting 12 different job analyses and what was more important 12 different rates, where only 1 rate for all the jobs had existed before. "Immediately," Brown says, "production declined and employee discontent increased. Upon further investigation it was found that the employees had always functioned as a team: the employees were capable of operating each other's machines: and the employees, therefore, expected the same rate of pay." Management, however, even when it had these facts, still supported the job evaluation plan. The union in the plant and the department foremen, it may be added, opposed its continuance.*

Nevertheless, the increased use of job evaluation during the war made it a major area of interest in cases coming before the War Labor Board.

On December 16 and 17, 1946, a conference of labor movement technicians and university people, whose primary interest was industrial relations, was held under the auspices of the Industrial Relations Center of the University of Chicago. This conference was unique in that it was the first time that such a conference had confined itself to labor movement participation. Although many management organizations had provided forums for labor movement spokesmen on the operation of different collective bargaining practices and the relationship between industrial engineering and collective bargaining on the policy level, this represented the first time that an all-labor group concerned itself formally with the industrial engineering problem.

The conferees discussed the four techniques of job evaluation:

1. Ranking.
2. Classification.
3. Point method.
4. Factor comparison method.

The conferees were unanimous in agreeing that the ranking and classification methods of job evaluation were nothing particularly new, and that the techniques had been used on an informal basis for a long time by trade unions in negotiating a general wage scale. Each rate is related to a specific job description. The principal problem around which most of the discussion centered was the feasibility of using more complex techniques for the same purpose. Three attitudes were discernible toward a proposal by management that job evaluation be used in setting up the wage

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* Reprinted by permission from *Labor Unions in Action* by J. Barbash (New York: Harper and Brothers, 1948), pp. 74-75.

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File Code FC 0320

Department Butt Weld Furnace Job Title (Std.) Roll Setter

Sub Division Butt Hot Ends Job Title (Plant) Roll Setter

September 3, 19-- JOB DESCRIPTION

Primary Function

Change rolls and adjust, to guarantee Buttweld pipe of proper O.D. size

TOOLS AND EQUIPMENT:

Sizing rolls - with troughs and controls.
Scaling rolls with troughs and controls.
Wrenches, hammer, bar gauges, puller, scale, and miscellaneous hand tools, etc.

MATERIALS:

Buttweld pipe of various sizes and lengths.

SOURCE OF SUPERVISION:

Hot End Turn Foreman - Routine job check up.

DIRECTION EXERCISED:

Directs Roll Setter Helper on working procedure.

WORKING PROCEDURE:

This occupation is of major importance because Roll Setter sets up and adjusts rolls which impart final size to Buttweld pipe and must continually check for maintenance of proper setting. The rolls must be set to size with close tolerance.

Place rolls in sizing and scaling machine - (lifted by crane and guided by hand.)
Set rolls to insure proper sized pipe.
Set guides to groove of mill.
Check quality of product and notify First Weder of burned or caved welds.
Check quality of Saw Cutting - if poor, notify Foreman.

The above statement reflects the general details considered necessary to describe the principal functions of the job identified, and shall not be construed as a detailed description of all the work requirements that may be inherent in the job.

FIG. 17.1a SPECIMEN EXAMPLE OF JOB DESCRIPTION AND CLASSIFICATION (FRONT SIDE).

scale. These three attitudes may be categorized as follows:

1. Complete rejection.
2. "Coyness."
3. Full joint participation in the installation and administration of the technique by both the union and the management.

The conferees were in agreement that under no circumstances could the job evaluation plan be used as the sole determinant of the relative wage structure.

JOB CLASSIFICATION

Job Title (Plant) Roll Setter File Code FC 0320

Factor / Reason for Classification	Code	Classi-fication
1. Pre-Employment Training. This job requires the mentality to learn to: Setup and adjust rolls - requiring a variety of adjustment.	B	.3
2. Employment Training and Experience. This job requires experience on this and related work of 19-24 months continuous progress.	E	1.6
3. Mental Skill. Setup rolls and make necessary adjustment in order to produce good finished product.	C	1.6
4. Manual Skill. Use hand tools in setting rolls to proper size and make a variety of adjustments to obtain proper O.D. of pipe.	C	1.0
5. Responsibility for Material. Estimated Cost: Under $250. Close attention for majority of a turn to make checks on product to insure proper O.D. - neglect to check frequently may cause production loss.	D	1.6
6. Responsibility for Tools and Equipment. Some attention required while making roll set-up to prevent excessive wear on rolls when processing pipe.	C MD	.7
7. Responsibility for Operations. Responsible for correct size and shape of pipe.	E	3.0
8. Responsibility for Safety of Others. Ordinary care to prevent injury to roll setter helper when making setup or adjustments.	B	.4
9. Mental Effort. Moderate mental application required - must recognize need for adjustments and correct immediately.	C	1.0
10. Physical Effort. Light physical exertion required. Check size, make minor adjustments. Use wrenches and bars when making roll changes.	C	.8
11. Surroundings. Hot in summer due to proximity of hot pipe, dirty, greasy work.	B	.4
12. Hazard. When checking sizes, roll setter is subjected to burns. When making changes in rolls, roll setter is subjected to severe cuts, bruises or fractures.	B	.4
Job Class 13 — Total		12.8

FIG. **17.1b** SPECIMEN EXAMPLE OF JOB DESCRIPTION AND CLASSIFICATION (REVERSE SIDE).

All agreed that among the factors that would have to be considered, aside from the relative job content measured by the job evaluation scheme in determining the final scale, would be such factors as:

1. Irregularity of employment.
2. The career prospects of the job—i.e., how high does the promotional sequence climb?
3. Market supply of a demand for specific occupations.

4. The traditional wage relationships which grew up historically.

There were three separate areas within which the job evaluation problem was considered:

1. The older, long-organized industries within which a long collective bargaining history has built up traditional wage relationships.

2. Old industries, newly organized, wherein a long history of lack of organization led to complete disorganization of rate structures.

3. New industries with new technologies, within which wage structures had to be developed without any historical precedents.

An example of the problem of job evaluation arising under the first category may be seen through the introduction of new technologies that change the relative skill content of different jobs—e.g., the introduction of section-work techniques into a sector of the women's garment industry where previously the complete-garment method of manufacture had prevailed. Traditionally, the method used to cope with this development was to set a single rate for all sewing machine operations; yet, it is obvious that the sewing jobs carry different skill values.

An example of the way the job evaluation problem arises under the second category—old industries, newly organized—is found in the telegraph industry. The union found the job rates completely jumbled because of the company's frankly avowed policy of purchasing labor in the local market at the lowest available price, irrespective of consistency or relative job content.

New industries, such as the plastics industry, without any historical precedents, present a joint problem to both the union and the management in developing a joint wage structure.

The following arguments were advanced in support of complete rejection of a job evaluation plan when proposed by the company. The acceptance of job evaluation encourages the process of job dilution. That is, skilled jobs are broken down into subsidiary jobs for no other purpose than to purchase cheaper labor. This process of job dilution takes place even though it has not been demonstrated that there is an increase in physical productivity as a result of the dilution. Examples of industries in which this is true were cited, such as the nonunion sector of the printing industry.

Another line of argument was that the job evaluation plans proposed by management hampered the collective bargaining process in the following fashion. Generally, every management proposal for job evaluation was related to some method of getting the area rate through local labor market studies. This was an attempt, the advocates of this point of view maintain, to graft the infamous industry-area wage theory first developed by the War Labor Board onto the new postwar economy. In addition, it was maintained that all these techniques were based upon unwarranted assumptions. For example, one of the assumptions was the existence of a permanent set of values by which the relative job content could be measured; next, that this set of values as expressed in the relative weightings assigned to different factors were the same for all types of jobs; that the yardstick created made no more sense than measuring the height of a building in terms of gallons of water. Finally, all the assumptions and tendencies of these techniques seemed to favor management instead of labor.

A good description of the coy or "show me" approach is found in the *U. E. Guide to Wage Payment Plans, Time Study and Job Evaluation:*

> Let the company use whatever method it pleases, but under close union surveillance. If the result is satisfactory, well and good; if it is not, the company will hear from us. The union should always reserve the right to challenge any job values which it finds unsatisfactory, and to utilize any and all factors bearing on the case.*

* *U. E. Guide to Wage Payment Plans, Time Study and Job Evaluation,* United Electrical, Radio and Machine Workers of America, 1943, pp. 77-80.

This stand-off approach was used with some success by the United Automobile Workers Union, CIO, and the AFL Meatpackers Union. The primary usefulness both groups found for the technique was as a means of securing increases that were otherwise impossible from the War Labor Board. The AFL Meatpackers permitted the employers to offer proposed rates on the basis of the management's job evaluation plan and then introduced other factors independent of the job evaluation study in order to adjust rates which they felt intuitively were out of line. A similar approach was taken by the CIO Meatpackers Union, which felt in addition that few unions could afford joint participation because almost all unions are handicapped by the lack of competent technical personnel vis-à-vis management.

The arguments advanced in favor of joint participation were as follows:

1. Most of these over-all plans, such as ranking and classification, actually consist of a subconscious breaking down of the over-all job into subsidiary factors. It is just as well to formalize and recognize consciously what is being done unconsciously. It is conceded that most of the management plans are technically defective in their pro-management bias. The remedy lies in union-developed plans that will serve as counterproposals to the management plans. For example, in the conversion of the job hierarchy into a wage scale, the concept of the going area wage rate is completely rejected. It is insisted that different weightings of factors be adapted to the requirements of different departments.

2. The problem of setting relative wage scales within a plant is not a problem confined to the management-employee relationship. In formulating the demands of the union upon the employer, the union finds itself immersed in the conflicting claims of the various groups as they compete with one another for their share of the expected total increase. Thus, the union may find itself in need of some common measuring stick, however limited it may be, which will provide means of resolving disputes among its own members.

3. Finally, preference was expressed by the advocates of the joint participation program rather than the stand-offish approach, because the union finds itself in a position where it has to confine most of its arguments within the framework of the management's job evaluation structure, because it lacks any other criterion upon which to base its arguments on relative job content. It was felt that it was much better strategy to be "in on" the project at the very beginning and lay the basis for the union's position in terms of what it wants in the job evaluation system.

Although many unfortunate examples were cited in which unions had found themselves in trouble after agreeing to joint participation in plans whose implications they neither foresaw nor understood at the time they entered them, some successful examples of joint participation were cited as follows: The United Steel Workers Union of America, CIO, jointly negotiated an industry-wide job evaluation point plan which is being used to resolve the problem of wage inequities. The engineer in charge of the project indicated that in 1942 there were 16,000 wage rate classifications at Carnegie alone. When first approached by U. S. Steel to use a job evaluation system to resolve these inequities, the union representatives turned it down because they feared it. In 1944, the union demanded similar pay for similar work. The War Labor Board virtually ordered the use of a job evaluation system. The union sat down with the corporation and devised a manual of job descriptions for all of basic steel. Along with it, the union and the company's engineers devised a point plan that both parties felt would serve their common purpose. The manual was first applied to a plant in Gary, Indiana. After some revisions, the manual was adopted and is now universal in basic steel. Stewards and union representatives are trained in its use. The union does not care to go back to the old system, under which no sooner had

one inequity grievance been solved than another appeared in its place. This method of "beating" rates up disorganized the union even more than the company. Since provisions were made for transferring those whose skill has been rendered obsolete to better jobs or for retaining the former and higher wage rate, there have been almost no complaints. The principal problem that remains unsolved in this installation is that no formal provision is made for raising the whole basic wage structure automatically from the savings that accrue from re-defined jobs requiring less skill under new technical processes than the old ones.

Another example is the experience of the UAW-CIO in a particular case. Because the union had agreed with the company on the installation by a joint committee made up of union and management representatives of a factor comparison method of job evaluation, the union was able to prevent the use of inequities as a basis for wage reductions. The union representatives, by a judicious choice of the key jobs under the factor comparison method, were able to insist upon a wage conversion line that would have yielded the group a 12 per cent increase in wages. The company demurred on the very job evaluation system whose installation it had itself suggested, because it objected to giving the increase.

As indicated by the excerpts from the author's report of the University of Chicago Industrial Relations Conference, the disagreements within the labor movement were vigorous, and became the subject of debate among leaders and technicians. Each union, however, shaped its attitude and practices in the typical American pragmatic fashion of solving specific collective bargaining problems. No attempt was made to impose upon the movement an over-all ideological philosophy of job evaluation.

In the late 40's, psychologists as well as engineers entered the field and under the leadership of men like C. H. Lawshe of Purdue challenged many of the techniques of the engineers. The generalized trade union attitude toward job evaluation following the appearance of this literature is best understood by including the writer's paper that appeared in the *Journal of Applied Psychology* in February, 1951:

A Trade Unionist Looks at Job Evaluation

A trade unionist's attitude toward job evaluation is largely governed by his estimate of its effectiveness as a collective bargaining tool. Collective bargaining is the embodiment of democratic practice by which workers exercise a voice in their working conditions. Job evaluation is a subordinate gimmick. The interest of the trade union in the relative differentials received by workers on different jobs is apparent to anyone possessing some insight. No union will be content to negotiate blanket base wages and then leave the distribution of the relative increments exclusively to management. Discussions about the relative effectiveness of job evaluation programs with or without union participation make about as much sense to the average trade unionist as a tract upon the relative effectiveness of marriages with or without grooms.

Trade unions are suspicious of proposals to correct large inequities particularly in first negotiations. Somehow, many of these inequities, it has been discovered, arise from the strategic increase. The foreman reports where the union is making organization progress during the campaign. "Inequities" are discovered in this department and increases ordered. In this way relative wages reflect the attempt to defeat the union. The union when asked to agree to correcting inequities in such a situation is likely to reply: "You were satisfied with non-union confusion for a spell. Show us your good faith by putting up with trade union chaos for a while. We'll discuss it in future negotiations." Later on, of course, these inequities raise internal problems for the union as relationships between the union and management become stabilized. It is then that the union may be ready to discuss job evaluation.

Psychologists have now entered the job evaluation field. It is no longer the exclusive province of the industrial engineer. Before a trade unionist can ex-

amine or evaluate intelligently their contribution to the field, it might be useful to delve into the very foundations upon which the technique has been built. It will, therefore, be my intention to examine in some detail two principal questions: (1) How does the unionist's concept of the function of job evaluation compare with the set of ideas held by management; and (2) How closely do the measuring techniques developed by both psychologists and engineers actually perform the function claimed on their behalf by practitioners in the field?

A job evaluation program will generally be proposed to a union as a technique for rationalizing the wage structure. It is based upon the western philosophy that men should be compensated according to the worth of the job they perform. Different jobs call for men with different capacities. Management feels that differentials in income should reflect the demands that these different jobs impose upon different men's capacities. This is at least what they say. The trade unionist is not so sure that they mean it.

We can all agree that the wage scale should begin at the bottom of the ladder with the job that makes the fewest demands upon anybody's capacity. Let's pick such a job at random, say that of a janitor. Now any man who takes a janitor's job brings to it the very minimum capacities specified in most evaluation schemes. But let us compare the capacities required by the janitor's job with those required by the president of a giant corporation, the modern industrial genius.

Morris Viteles has some interesting things to say about the relative capacities of the two groups from which respective candidates for these positions are drawn. He wrote "The difference between the general intelligence required of the janitor and that demanded of a highly skilled worker or top superior appears to be well nigh limitless. Actually in terms of numerical values, the general intelligence of the successful employee in such a top job is seldom found to be more than three times that of the most stupid worker in the least responsible job. This ratio of 1-3 between the extremes of ability and an even lower ratio of less than 1-2 for physical measurements, measures of motor function, etc., recur with striking frequency in studies of individual differences in ability, skill and other human traits. Very seldom is the ratio greater than 5-1." [Morris S. Viteles, "A Psychologist Looks at Job Evaluation," *Personnel*, Vol. 17, 1941, 165-176.]

The implications of these conclusions for job evaluation are quite obvious. No job can be worth more than the maximum capacities a man is expected to bring to a job. On the other hand no job can be worth less than the very marginal capacities a minimum human being must of necessity bring to a job. If the president of a great corporation seriously believes that he wants the pay scale based upon the relative objective value of a job, then he is obliged to take for himself no more than five times the hourly rate which he pays to the lowliest employee in his establishment.

The trade unionist has discovered that the corporation executive will not be satisfied with such an arrangement. It is fruitless to expect complete rationalism in a wage policy when almost all other economic policies possess irrational elements. Pricing policies are not always based upon cost. De luxe models of appliances are marked up more because of the average consumer's willingness to pay more rather than in proportion to the extra labor cost and materials in de luxe models. It is for reasons like this that trade unionists are exceedingly suspicious of this desire to rationalize only one element in the economic picture, the wage structure. Suppose that $300.00 were to be divided between two men rationally. One man possessed a relatively low intelligence, the other man a relatively high intelligence. The former was phlegmatic and indifferent, the latter aggressive and ambitious. As Viteles remarks, the ratio of this combination of traits could be at the most 1-3. Would the distribution of this income be divided in the ratio of $75.00 to $225.00 or would the man with the high pugnacity coefficient and the intelligence to match it go off with the whole $300.00? His intelligence might lead him to leave the victim about $10.00 to make sure that his rival would not be goaded into revolt. Now just multiply the man with the low pugnacity coefficient by millions and we have a much better explanation of why incomes are distributed the way that

they are than any high flown theories about relative contributions to society.

Attempts to rationalize this distribution can be made. For one thing we are told that executive jobs can't be measured on the same scales used for factory jobs. This argument of course is confined to advocates of a point system. Advocates of the factor comparison method assure us that they can use their system for jobs right up to $30,000.00 per year. [E. N. Hay, "Characteristics of Factor Comparison Job Evaluation," *Personnel*, Vol. 22, 1946, 370-375.] Non-linear wage curves resembling the exponential function are presented to justify the steep increases in wages that are presented to the public. However, although recognizable ability increments are recognized in geometrical relationships, the overall ratio between top and bottom still can not or should not exceed the ratio of 1-3 or 1-5. Compare C. E. Wilson's salary of General Motors with that of a porter and what do you get? The point plan advocates who inform us that plans like the NEMA are not adapted to the measurement of executive positions, nevertheless maintain that their rigid common measuring scale can measure the relative requirements of sewer workers and tool makers. More about these measuring techniques later. The only rationale that can be advanced to justify such a curve is that it reflects the small "genius supply" in the population. Supply and demand, however, does not enter into job evaluation plans.

You may now assume that I am opposed to job evaluation. But that is not the case at all. I do not believe, and I do not think that management believes, that it is the function of job evaluation to compensate workers in accordance with the so-called value of the job. I do not believe that job evaluation can be used as the sole determinant of how to build a relative wage structure. It is but one of the many factors that enter the collective bargaining picture in fixing a final wage scale. It is a device to measure relative job content and nothing more. This relative content is just one of many factors that contribute to the building of the final wage scale.

As indicated previously, some of the other factors that I have in mind are as follows: (a) irregularity of employment; (b) the career prospects of the jobs; (c) supply and demand; and (d) the traditional prestige carried by the job in the plant social system.

For example, two jobs "A" and "B" may carry the same point assignment. "A" job exists only during the tooling up period. "B" continues right through the production season. A union may ask for more money for job "A" for this reason. Then again, what is it that leads a young chemical engineer with all his training to work for less wages than a plumber? Some of it, of course, is a rather silly concept of a contradiction between unionization and professional status. The other part is the young engineer's willingness to pay back a part of his legitimate return in the hope of serving his apprenticeship for what he hopes will be works manager.

Supply and demand is a factor that is often overlooked. Naturally unions exist to protect workers against being victimized by being compelled to compete with one another like so many bushels of wheat; but let's take a look at another part of the picture. During the war the War Labor Board had fixed the wages of foundry hands at seventy-five cents per hour. This was done on the basis of a job evaluation plan approved by the board. There was no strike. The supply of foundry hands disappeared as the old foundry hands sought employment elsewhere. Of even further interest was the fact that increased wages failed to increase the supply of foundry hands. Foundry hands traditionally had been at the bottom of the factory social ladder and nobody wanted to stay there even at an increased price.

A further investigation of the interfering influence of the factory's social system with job evaluation conclusions are seen in what revaluation sometimes does to the promotional sequence in a factory. A job at the very top of the promotional ladder is devalued and with it all the aspirations of a group of men who had hoped to occupy that job. After all, the fundamental purpose of job evaluation is to establish a mutually acceptable criterion of equity. If both worker and supervisor agree that, for example, the cementers are the aristocrats of the raincoat industry, what useful purpose is served by upsetting this scale of values in favor of some mechanistic criterion of equity? These traditions are every bit as important as job con-

tent. What this all adds up to is that in erecting a structure of relative wages there will be any number of rates which must be considered. There are: (1) the job evaluation rate based on relative job content; (2) the comparative rate for the same job in other industries in the same area; (3) the comparative rate for the same job in the same industry in the same area; (4) the comparative rate for the same job in the same industry in other areas; and (5) the comparative rate for the same job in other industries in other areas.

For example, suppose the rate for a machinist in the "X" automobile factory in Squeedunk is $1.65 whereas the rate for a machinist in the "Y" textile machinery works in Squeedunk is only $1.25. Again the machinists' rate in the rival "Z" automobile factory in Squeedunk is $1.75, whereas the machinists' rate in the "N" automobile works in Podunk is $1.95. Still again, the machinists' rate in the "M" textile works in Podunk is $1.45. Thus, for the single job of machinist we have five separate rates, any one of which can be justified upon some concept of equity. The job evaluation rate is only one of these five. Collective bargaining is the method used to satisfy both parties that there has been equitable consideration of rival claims.

Now that we have established that job evaluation is just one subordinate tool of the collective bargaining process, let us proceed to an examination and evaluation of the different methods proposed for measuring relative job content.

It would be fruitless to attempt to examine all job evaluation techniques in the space at my disposal. I should like to confine my remarks to comments on the point and factor comparison techniques. It has been interesting to note the contributions of psychologists to this field. Lawshe and his students, Bellows, Chesler, Edwards, Hay, Otis, Rogers, and Turner have examined existing systems and proposed others. In the course of commenting upon these different plans it will be the writer's intention to provide a trade unionist's reaction to their significance.

The most widespread plans in use today are the point plans such as the National Electrical Manufacturers Association (NEMA) plan. This plan lists eleven factors and weights each factor on the theory that this weighting determines the contribution of that particular factor to the final result. This weighting is supposed to determine the effect of the corresponding factor in the final relative distribution of these jobs. Tiffin [*Industrial Psychology*, 3rd ed. (New York: Prentice-Hall, Inc., 1952), pp. 337-342.] disclosed the fundamental fallacy in all additive point plans in his comments on merit rating. He pointed out that it was not the maximum ranges of possible points that determined the relative weights of any one factor in the final result but the variability of the factor.

For example, suppose that I want to weight skill and working conditions equally. I allow a possible range of fifty points for each factor. However, suppose that I rate five jobs as follows:

	1	*2*	*3*	*4*	*5*
skill	5	45	30	20	15
working cond's	20	30	25	25	25

I have actually used a range of 40 points for skill and a range of 10 points for working conditions. The relative weights contributed by the 40 points will have approximately four times the effect of the 10 points contributed by working conditions. Yet, workers on job evaluation committees as well as technicians have been under the impression that each factor was playing a role equal to its pre-assigned weight in the final determination of the result.

Using the Thurstone factor analysis technique, Lawshe and Satter ["Studies in Job Evaluation 1. Factor Analyses of Point Ratings for Hourly-paid Jobs in Three Industrial Plants," *Journal of Applied Psychology*, Vol. 29, 1945, 197.] demonstrated the uselessness of the NEMA plan for its avowed purposes when they concluded that, "While there is considerable agreement from plant to plant insofar as the presence of factors is concerned, there is variation in the extent to which they contribute to total point ratings and consequently, to the existing wage structure. . . . It is clear that the extent to which each item or factor contributes to the total cannot be determined by inspection of the scale alone and that the end result may yield results different from those intended by the makers of the scale."

When they point out that under the

NEMA plan, skill demands varied from 77.5 per cent in one plant to 94 per cent in another, I submit that this is proof that the NEMA experts simply do not know what they are doing. It is for this reason that I am unable to understand the purposes of some of the other studies conducted by Lawshe. Job Evaluation Study 2 is an attempt to prove that other factor job evaluation systems will give substantially the same results as the more complex technique. Lawshe concludes from this study, "If the three item abbreviated scale were employed in Plant A, 62 per cent of the jobs would remain in the same labor grade, 37.2 per cent would be displaced one labor grade and 0.8 per cent would be displaced two labor grades. . . . A simplified scale consisting of three or four items would probably yield results that are practically identical with those obtained by a more complex system and would greatly reduce the time consumed by the rating activity." ["Studies in Job Evaluation. 2. The Adequacy of Abbreviated Point Ratings for Hourly-paid Jobs in Three Industrial Plants," *Journal of Applied Psychology,* Vol. 29, 1945, 184.]

I cannot take issue with these conclusions but I cannot help feeling that they are trivial. Since Lawshe has proved that the operators of the NEMA system only know vaguely, if at all, what they are doing, how important is it to conclude that there is a more economical way to do the same thing? Yet Study 3, Study 4, Study 6, and Study 8 yield substantially the same conclusions as Study 2, and therefore, are of as little significance as Study 2. [See D. J. Chesler, "Reliability and Comparability of Different Job Evaluation Systems," *Journal of Applied Psychology,* Vol. 32, 1948, 622-629; P. M. Edwards, "Statistical Methods in Job Evaluation," *Advanced Management,* Vol. 13, 1948, 158-163; E. N. Hay, "Characteristics of Factor Comparison Job Evaluation," *Personnel,* Vol. 22, 1946, 370-375; E. N. Hay, "Assuring Equal Pay for Equal Work Or Some Fallacies in Salary Evaluation and Administration," *Proceedings of the National Office Management Association,* 1946, 3-15.] Study 8 concentrates on the reliability of raters using the abbreviated scales. The conclusions of Lawshe in Study 2 have been independently confirmed by Rogers ["Analysis of Two Point-Rating Job Evaluation Plans," *Journal of Applied Psychology,* Vol. 30, 1946, 579-585 and Chesler (see above)]. However, Study 7 does raise the question of a suitable criterion against which to measure some of the results obtained from these abbreviated scales. Lawshe, Dudek, and Wilson conclude that "No conclusions about validity can be drawn from this study due to the lack of a suitable criterion. . . . Although short job evaluation systems consisting of only a few items may be statistically and logically justified, it may be practically advantageous to include additional items in the system which will make it more acceptable to raters and to employees." ["Studies of Job Evaluation. 7. A Factor Analysis of Two Point-Rating Methods of Job Evaluation," *Journal of Applied Psychology,* Vol. 32, 1948, 118-129.]

One of the principal complaints about point job evaluation systems has been their tendency to play down working conditions and physical hazards as important factors. Perhaps a more constructive approach would be to show both parties how to cease making old mistakes rather than claiming the old mistakes can now be made with less effort.

In my opinion, the most significant job evaluation plan in use today is the plan governing the inequity wage adjustment program of the Steel Corporations and the United Steel Workers, CIO. Paul Edwards who developed the plan used a modification of the factor comparison method to tailor a system to the needs of the Steelworkers. The method that he has used to root the plan in the existing wage structure of the industry calls for the use of correlation mathematics beyond the capacity of most workers to understand. However, the operation of the plan calls for simple rank additions and is readily understood by anybody with an elementary school knowledge of simple addition. The correlation mathematics was required to derive the weights for different factors resulting from past wage practices and collective bargaining experiences. He comments that "The actual rates developed by supply and demand and bargaining in years past have recognized the nature of the problem better than empirical job evaluation plans. The principal advantage of the plan is that it makes it possible to pursue systematically in the future the same set of values that have governed

both parties initially in the past." ["Statistical Methods in Job Evaluation," 161.]

The validity of the plan is based upon the satisfaction of collective bargaining experiences. Factor comparison methods of this nature lend themselves readily to such flexible operation and are therefore superior to point plans with their fixed ranges and unpredictable variability. I believe that the most fruitful research will come from this type of orientation.

SUMMARY

The trade unionist looks upon job evaluation as a subordinate tool in collective bargaining. It does not determine what a job is worth, it determines a limited concept of job content.

The final evaluation rates can only be one factor in determining what the relative wage structure should be.

Most job evaluation plans are exceedingly defective in measuring job content. Most abbreviated plans perform the same function more economically but are equally defective.

The most useful work in job evaluation is research designed to isolate the factors that have governed the intuitive operation of collective bargaining as each party sought its own concept of equity. These factors can then be used for future guidance.*

An outstanding example of the conflict between the logic of job evaluation and the logic of equitable wage determination may be illustrated by a discussion of the case of the administration of the job evaluation plan governing the Southern California Aircraft Industry (SCAI). This plan was imposed by the National War Labor Board ruling in March, 1943.

Clark Kerr and Lloyd Fisher have described in detail the problems that arose under the administration of this plan.

The most difficult and pervasive problem in the administration of job description and evaluation in the Pacific Coast aircraft industry arose from the frequent conflicts between measures of external and measures of internal equity. The price of a job in the market is one well-established measure of its worth. The SCAI plan established a different measure of its worth. The conflicts between these different standards made for continuous obstacles to the consistent administration of the plan. . . .

It was discovered both in Southern California and in Seattle that the plan overvalued skill in relation to the factors of job disutility, such as job conditions and physical application.*

In installing and administering a wage incentive payment plan, Kerr and Fisher issued the following set of significant warnings:

1. The higher the wage level of the plant, both relative to the community and in absolute terms, the more successful will the plan be.

2. A job evaluation plan must be devised and administered with one eye always on the market. Here is a major dilemma faced by job evaluation. If the evaluated rate falls substantially below the prevailing rate for any job with a clear counterpart in the community, the rate will fail to command the necessary supply of labor in a tight market.

3. If a job evaluation plan yields rates which are significantly higher than those paid by other employers for the same kind of labor, many informal pressures will be brought to bear to bring the rates "into line," and this will mean "into line" with other enterprises and not with other jobs in the same enterprise.

4. A single industrial union will prove more compatible with job descriptions and evaluations than will several craft unions.

5. If the employees of a plant are organized, it is highly desirable that any job description and evaluation plan adopted be agreed to and, if possible, jointly developed by the company and the union.

6. The terms of a job description and

* W. Gomberg, "A Trade Unionist Looks at Job Evaluation," *Journal of Applied Psychology*, Vol. 35, No. 1, February 1951, 1-7.

* C. Kerr and L. Fisher, "Effect of Environment and Administration on Job Evaluation," *Harvard Business Review*, Vol. XXVIII, No. 3, May 1950, 81, 88.

evaluation plan will be better executed under conditions of universal, or nearly universal, union membership than will be true if substantial groups of employees do not belong to the union. The opportunities for manipulation of the plan by the union for the advantage of union members and by employers for the advantage of nonunion members will be many.

7. On the management side, the plan is better administered by the industrial relations staff than by the wage or industrial engineers who may have designed it. The essence of successful administration is flexibility.

8. It is of major importance that the number of job titles and classifications be held to a minimum. The results of excessive elaboration of the job structure are many and unfortunate. They deprive management of flexibility of assignment.

9. A plan which provides for single rates and for specific ratios of A, B, and C workers in job families is easier to administer than one which calls for rate ranges and sets no fixed ratios.

10. Over a period of time it will prove difficult to retain the heavy weighting which is given to skill factors in the SCAI and many other job evaluation plans. There are influences operating which will require that greater weight go to the disutility factors such as hazards, physical effort and job conditions. It seems probable that skill has much greater weight at the commencement of job evaluation plans than can reasonably be expected of their later phases. During periods of expansion, the most urgent employer demand is for skill. Many of the present job evaluation plans had their birth in such a period with the consequence that skill factors commonly account for half or more of the total rating points in a plan. But when the plant is constructed, the machinery built, the process installed and rationalized, the demand for skilled workers met, and relative scarcity manifests itself in the semiskilled and unskilled classifications, tendencies toward the devaluation of skill will appear.

In the long run the tendency may be even more pronounced. As the general educational level of the industrial workers rises and as the opportunities for skilled work decline relative to the semiskilled classifications (a clearly defined trend over several decades now), more weight will have to be given to the elements of disutility in a job rather than to those of skill.

11. Custom is a powerful force. The absence of historical practice in the case of SCAI greatly increased the original conflict over the location of jobs on the scale of compensation.*

The authors finally concluded as follows:

Job evaluation faces its gravest threat from the monolithic character of the value system it assumes. For at base all job evaluation systems attempt to measure the relative worth of a job by ascribing given exponents of value to such characteristics of the job as skill, hazard, job conditions, and the like. The more fixed and definite and self-executing the formula, the less will it allow for the other and perhaps more important pressures to which job rates respond.

Job evaluation as a system of rate setting tends to meet only one of many criteria of equity; and the more decisive the considerations of job evaluation become, the less likely is it that other criteria of equity will be met.

It is a reasonable surmise that had the SCAI plan been more exact, less subject to manipulation, it would have been less successful in preserving labor peace There are important elements of conflict and even contradiction between technical criteria, on the one hand, and economic and institutional criteria, on the other. The area for manipulation was also the area of indeterminateness of the plan. This area of indeterminateness provided the necessary scope for the satisfaction of economic and institutional objectives.†

The underlying theory behind the application of job evaluation and the West Coast aircraft industry had its repercussions in an arbitration between North American Aviation, Inc., and the United Automobile, Aircraft and Agricultural Implement Workers of America (CIO). The board of arbitration consisted of David L. Cole (chairman), Benjamin

* Kerr and Fisher, "Effect of Environment and Administration on Job Evaluation," 91-93.

† *Ibid.*, pp. 94-96.

Aaron, and W. Willard Wirtz, appointed by the President of the United States.

The outcome of this decision was that the

> . . . employer's contention that adjustment should be determined strictly by comparison with rates paid by other airframe companies in the area in accordance with established bargaining pattern is rejected.*

In other words, the concept of wage equity not only transcends the internal controversy within a plant but even within an industry.

A review of the attitudes of trade unionists toward job evaluation can be seen to vary widely. The one proposition upon which you are likely to get unanimity is that they will not leave the relative wage scale to the blind operation of techniques. The more craft-conscious unionist will dislike it even more than the industrial worker-minded trade unionist. The very concept of job evaluation encourages the dilution of the craftsman's skill and is a threat to his status in the work hierarchy.

5. TIME STUDY AND COLLECTIVE BARGAINING

Reference to the Labor Management Conference of 1945 has already been made. The specific management function which representatives of the employers insisted must remain a management function alone was the setting of production standards. The rationale for this position was laid down at the time by professional leaders like J. S. Louden and Phil Carroll. The rationale could be stated as follows:

> . . . A standard must be based only upon facts and changed only by facts; therefore, standards must not be subjected to negotiation or arbitration in their establishment or in their change.†

* *Labor Arbitration Report*, Vol. 19, 1952, p. 77.

† W. Gomberg, *A Trade Union Analysis of Time Study* (Chicago: Science Research Associates, 1948), pp. 12-13.

L. H. Hill and C. R. Hook, Jr., taking their cue from the position of the committee on management's right to manage, concluded that·

> . . . While labor's right to question the production standard may be entertained as a grievance, the grievance terminates with the management. It is non-arbitrable.*

This meant that the labor movement was obligated to perform three tasks:

1. To develop a philosophy of time study that would either lead to its total rejection or reconcile its use with collective bargaining practice.
2. To impose upon or persuade management of the validity of its philosophy of time study.
3. To develop collective bargaining practices and procedures based upon this philosophy to implement its objective in actual practice.

No formal statement is available from which any over-all attitude toward or philosophy of time study can be attributed to the entire labor movement. Different trends of thinking are found in the different unions making up the labor federations. Many of these past trends are found in the summary of proceedings of the first all-trade-union technicians' conference on the application of industrial engineering techniques to collective bargaining. We have already made reference to this conference, which was held under the auspices of the Industrial Relations Section of the University of Chicago, December 16th and 17th, 1946.

The record of the conference report is as follows. Representatives of those unions whose bargaining position was not strong enough to compel management to acknowledge officially the equity of the workers in setting a production standard found that the management actually did negotiate production rates on the operating level. They put it in the following terms. Top management and its legal staff hand down a policy and contract to the actual operating officials who have

* *Ibid.*, p. 13.

to get out the production. These operating officials know as a practical matter that if they attempt to set the rates unilaterally, they will be bedeviled by disturbance after disturbance, and production will be cut down. The result is that standards are negotiated unofficially. This approach is found in many areas of the auto industry.

After agreement had been reached upon this fundamental doctrine of the labor union's equity in the matter of setting the production rate, opinion on subsequent points differed. Trade union technicians observed that the problems that develop under time study vary widely according to the type of industry under review. These may be classified roughly as follows:

1. The problem of rate-setting in industries where the processes are machine-paced and automatic.
2. The problem of rate-setting where the processes are man-paced and the machine is but a power-driven hand tool (if any machine at all is used).
3. The problem of rate-setting in service industries, where it is difficult to find any meaningful measure of productivity.

A typical example of the first problem is the textile industry, in which machines are fully automatic and where a worker's job may be to repair a thread breakage or machine breakage when the machine is down. It should be noted that the worker is active during the non-producing cycle of the machine's operation.

Good examples of the second problem under type number two are found in the garment industry. In this industry, the sewing machine operator controls the speed of output. The sewing machine is generally speeded so far beyond the operator's capacity that its full possibilities are seldom utilized.

The type of problem arising under number three may be seen in the building service industry, where attempts must be made to standardize the work task in terms of area cleaned.

The problems offered by man-paced operations are generally much more difficult to solve than those which have a fixed machine pace. More often than not, the wide adaptability and variability in human performance completely escape an engineering solution. Then again, it should be remembered that each of these categories of problems does not fit into water-tight classes. A good example of overlapping is found in machine shop work. In analyzing any of the common machine shop jobs, such as milling, the different classes of elements may be classified as set-up time, cutting time, and put-away or cleanup time. The set-up and put-away times are man-paced. The machine cutting time is fixed by standard feeds and speeds. The machine cutting time can be determined with a good deal more accuracy by the engineer than can the two man-paced elements.

The following points of view were discernible among the conferees:

1. Complete rejection of time study techniques as a guide to the setting of a fair day's work.
2. Consideration of the rate proposed by the time study engineers as an offer. The union reserves the right to determine whether or not it will accept the offer by any criterion, time study or otherwise, that it sees fit.
3. The joint acceptance of a time study system mutually satisfactory to union and management as a means of setting rates.
4. The development of a system of standard data that will serve as a basis for rate-setting.

Proponents of the first point of view denied any validity whatsoever to the time study technique. They indicated that the wide number of variables, all subject to human judgment, which could influence the final rate result so markedly, made the time study all but useless. Still others indicated disagreement with the very assumptions upon which a job description was standardized in order to make time study possible. They claimed that there was no one best method for all workers in performing a given operation. The more complex the job became, the less possible it was

to standardize an elemental job description that every person could be expected to follow. They pointed out that this whole theory flew in the face of all that the psychologists had found out about individual differences. In short, they took very much the same position first developed by Ernest Farmer in his evaluation of time study for the British psychologists.*

The attitude taken by most unions employing this approach is that the employer has a right to expect a reasonable effort during the working day without any limitation on the amount of production expected. Industries where this point of view prevailed were the photoengravers and the railway clerks.

Others of the conferees, though conceding the soundness of these objections to the time study method, nevertheless contended that unions must adapt the technique to their purposes until such time as they can offer an alternative method of measuring a "fair day's output."

One group took very much the same attitude toward time study as was taken by Carl Barth. Carl Barth, who was Taylor's associate, described the accuracy of time study in the following terms:

> . . . It is hardly conceivable that two time study men, however well equipped by training and experience and with physical means, would arrive at exactly the same time allowance for any job each might in turn be inadequately assigned to study. And still, the time allowance of either would be undoubtedly fully satisfactory for use in establishing a fair contract between the worker and the management, though the two would not be identical.†

The one revision that would be demanded by the union officer is that the contract be bilateral instead of unilateral. In testing the acceptability of the management's offer, however, the union officer may wish to be guided either by his own experts' time study methods or by historical production rates. In any case, he will not reject the management's offer because it is a time study offer. At the same time, he will not be constrained by the technical practices of the management. He is willing to concede the initial rate-setting process as a management prerogative. This is the practice of the garment workers in areas where standard data are unavailable.

Others have gone somewhat further in jointly determining the technical criteria for many of the time study systems. For example, the steel workers had agreed with the U. S. Steel Company in past agreements that a working rhythm equivalent to the pace maintained by a man walking three miles per hour shall be considered normal. Similarly, other variables, such as the fatigues and downtime allowance for different jobs, are likewise negotiated. The auto workers also indicated that they used this approach in many cases. Similarly, other groups have attempted to circumvent the harrowing day-to-day arguments about production rates by joint programs to set up standard data. These standard data consist of assigning a standard time allowance to standard tasks that recur over and over again in different work patterns. The production standards for new products are developed by adding the times for these various standard parts. Thus, the New York Dress Joint Board of the International Ladies' Garment Workers' Union settles production standards on the basis of a table developed by engineers jointly retained by the management and the workers. It is revised periodically by the joint machinery set up to administer the program.

Workers in the service industries, such as the Building Service Workers Union, usually accept the job standards that they find in practice when the building is organized. Attempts to increase this work load are resisted. However, they pointed out that when they sign up a newly built structure, the union must

* Ernest Farmer, "Industrial Hygiene," *Time and Motion Study Journal,* Vol. 4, No. 4, August 1922, 134-189.

† *Symposium on Stop Watch Time Study,* p. 108.

propose a standard of work for its own protection.

Objection was voiced to management offers to train union time study technicians. The trouble was that these training courses were seldom thorough examinations of various techniques, but mainly an indoctrination in the truth of the particular clerical techniques employed by the particular engineering organization. Instead of able union time study technicians, these courses turned out hostages for the particular time study prejudices of the teacher within the union's ranks. All were agreed that if the union required technicians, it was the union's job to train them independently, or in cooperation with a sympathetic university.

In order to pursue its objectives and establish its validity before arbitrators and the NLRB, technicians of the labor movement have developed a philosophy of time study. The central conflict between the management technicians and the labor movement technicians takes place over whether or not past performance or existing performance is any guide to future performance.

The issue was spelled out in a paper delivered by the writer before the Industrial Relations Division of the University of California on Saturday, February 3, 1950. Pertinent abstracts follow.

> Almost every discussion about union-employer problems of production standards starts with the members of both groups in agreement upon two fundamental principles which they both publicly acknowledge.
>
> Ask a union leader what he believes or ask an employer what he believes. In each case you will get the bromide, "I believe in a fair day's work." If either the employer or the trade unionist feels any concern over the opinion of the members of the academic world, then this bromide will be followed by its corollary platitude that production standards development requires no haggling but merely determination of facts. Facts. What a hard nugget of a word. It sounds so austere standing there as a cold, hardheaded challenge to the alleged emotional hysteria attending a high-pressured bargaining session.
>
> A fair day's work operationally tells us nothing. It is a pious moral expression.
>
> Nobody is against it and when anybody comes out in favor of it he has said precisely nothing. A fair day's work only acquires meaning when both the employer and the worker have reached an agreement. It is an equity concept. It no more means the full expenditure of all the worker's energy short of exhausting illness than does a fair wage mean the full expenditure of the employer's funds for wages short of bankruptcy. Engineers generally approach the question of wages and work standards as two separate questions. The argument generally follows the ensuing pattern. The amount of work expected of a worker is a scientifically measured variable based upon facts. Wages, it is conceded, at least since the unions have become strong enough to insist that they be heard, is a matter for bargaining. The key word here, of course, is facts. But what is a fact?
>
> *A fact is a selective description of a total experience.*
>
> The phase of experience which is emphasized in our so-called facts depends upon the particular set of prejudices that each one of us brings to our observation post. Let me cite some specific examples.
>
> One of the truisms with which the average time study engineer is indoctrinated very early in his career is that work rates should not be based upon past performance but upon time study. Now past performance constitutes a very sound body of facts which can be analyzed statistically to detect the characteristics of the work place, the nature of the job and the working environment producing the work standard. The engineer, however, is guided by a set of value judgments which leads him to reject this set of facts in favor of a different set of facts. He wants more production from the employee and so his set of facts is derived from motion study principles which he is inclined to view as immutable and unchangeable. The gestalt psychologists and the English school of industrial engineers who have come under the influence of Gillespie

reject this set of facts as at best limited; at worst, false.

. . .

I submit that it is impossible to consider the matter of a fair day's work scientifically without the specification of a wage, both its amount and its system of payment.

The development of scientific production standards must depend upon the derivation of a sound statistical sample from a distribution of work times. These work times if they are to yield a sound, meaningful, statistical sample must, in turn, come from a statistically stable parent population.*

This reasoning rests upon the same application of probability to time study phenomena which Shewhart applied to quality control. Technicians of the labor movement have pioneered this thinking and are now joined by some members of the academic world. Some dispute these findings; others support them.

It is important to remember, however, that we can conceive of a state of statistical control although we know of no way of obtaining such a state of control in practice. As Shewhart states: "The delineation of such a concept is a priori and definitive whereas the application of the concept to a particular given physical state of control is hypothetical." †

Our ultimate objective is to be able to define a state of statistical control for a time study system, in terms of a physical cause system and the quantitative characteristics of the sequence of observations produced by such a cause system.

It is quite apparent that before we can predict from any observation what representative time a job requires, the worker-machine system must be in a state of statistical control.

Thus, the problem of developing a sound time study system resolves itself into answering the following questions:

1. On the basis of an a priori examination of the physical cause system underlying production rates in a normal industrial environment, to what degree are we justified in assuming that these causes can be stabilized to an extent where we can postulate that all remaining variations are attributable to a constant chance cause system?

2. What are the quantitative criteria which time study can use in detecting the existence of such a state of control from a series of time study observations?

3. Can these statistical tools be used for purposes of approximation in industrial time study in the event it is found that a constant chance cause system does not characterize the industrial environment?

The answer to the first question lies in a detailed examination of all the sources of variation. This calls for investigations into engineering to determine the mechanical effects, to the field of physiology to determine the possibilities of stabilizing the physiological effects, and finally to psychology and sociology for the effects attributable to these specialized fields.

The answer to question two calls for an examination of the field of mathematical statistics as they were first applied by Shewhart to quality control.

The answer to the third question lies in determining to what extent the industrial environment can be brought under a constant chance cause system.

Now let us assume that questions one and three can be answered in such a way as to justify a possible state of statistical control. The author's own answer may be found in his *A Trade Union Analysis of Time Study*.* It is important to

* W. Gomberg, *Union Problems in Setting Production Standards*. Paper delivered before the Institute of Industrial Relations, University of California, Berkeley, February 3. 1950.

† W. A. Shewhart, *Statistical Method from the Viewpoint of Quality Control* (Washington, D. C.: Graduate School, Department of Agriculture, 1939), p. 11.

* W. Gomberg, *A Trade Union Analysis of Time Study* (Chicago: Science Research Associates, 1948).

remember that any solution that is advanced must conform to a minimum accuracy of plus or minus 5 per cent, the usual minimum increment or decrement to the payroll in collective bargaining.

The types of relationship that require study in rate-setting in order to establish the existence of a statistically controlled universe of data are:

1. The internal relationships of the time study readings of a single person during a fixed interval of time.

2. The relationship of sample frequency distributions of a single person at different times during the working day.

3. The relationship of sample frequency distributions of a single person on different days.

4. The relationship of frequency distributions of different people on the same job.

Adam Abruzzi* took the actual application of this statistical approach and translated it into operating terms. In summarizing Abruzzi's work the writer said at the University of California, February 3, 1950:

> Abruzzi has taken up the operational implementation of many of the statistical criteria for scientific time study which I proposed some years ago in my own trade union analysis of time study. He has gone far beyond the boundaries that I drew at the time and has developed many valuable theoretical concepts of his own. The empirical materials for many of his conclusions were gathered in factories under contractual relationship with our union. The operations in our factories are mostly man-paced without any interfering fixed machine cycle. Thus, an excellent opportunity was provided to conduct these researches. Our own union's interest in these conclusions is obvious. I cannot in the short time allotted to me do justice to Abruzzi's over 300 pages of manuscript. I do hope to examine some of its significant highlights.

It would be fruitful to examine the answers to two time study questions proposed by Abruzzi; it is even more important to investigate the methodology by which these answers were derived. These two questions are:

What are the criteria which may be used to determine that a process is standardized and ready for a time study?

What constitute meaningful summarizing statistics of time study data?

The philosophy of Abruzzi's approach to the analysis of time study data may be summarized as follows: "Subjective procedures of rating current productive rates to predict the time of a theoretical normal worker have no function in an objective methodology."

This of course means two things in terms of union policy:

(1) Subjective rating procedures are rejected as objective determinants of a so-called scientific production standard in collective bargaining.

(2) So-called scientific studies such as the rating project conducted under the auspices of the Society for the Advancement of Management are rejected. The distribution of the subjective prejudices of the industrial engineers of America about what they would like to be a normal working speed is an interesting game but hardly a serious objective investigation.

Inasmuch as the labor movement was not even consulted on the original design of this investigation, we can only regret the waste of so much good energy. Pointless questions, however, still can elicit only trivial answers. This is true even when they are supported by impressive academic credentials. It is not a matter of the sincerity of the investigators, for whose integrity I have the highest regard. It is just a matter of the logic of the questions which they ask. Now this, of course, does not mean that rating of time studies is excluded from collective bargaining; it merely means that in the absence of more objective criteria, the rating remains a subject for collective bargaining. When it comes to prejudices I am confident no one will begrudge us our own.

Let us now talk about standardization of the job. When is the job ready for a

* Adam Abruzzi is associate professor of Industrial Engineering, Stevens Institute of Technology, Hoboken, New Jersey. His book, *Work Measurement* (Columbia University Press, 1952) is based upon research in factories in contractual relations with the International Ladies' Garment Workers' Union.

time study? An examination of the literature discloses qualitative descriptions that vary from one extreme to another. One authority demands virtually the performance of a micro-motion pattern that satisfies the micromotionist's concept of the most economical combination of elemental motions. Others, like Carrol, are all for taking the study on the job just as it is found. They feel that the job pattern can never satisfy the demands of the perfectionists and tend to the other extreme.

Abruzzi departs from these qualitative descriptions and merely asks one question: Do the performance times of the workers satisfy some rational operational criteria of statistical stability? He has defined this stability on two levels, local stability and grand stability. Local statistical stability is measured in terms of the variation in production times over a continuous series of items made over a few hours or at most a continuous day. Grand statistical stability is measured in terms of the variation in production rates of a series of small samples taken over an extended time interval from increments considered qualitatively to be taken under essentially the same conditions.

The criteria for local stability consisted of building up Shewhart control charts for the means and ranges from as many as 70 subsamples, consisting of three items each, from a total of 210 continuous readings on a single individual. This was done for individual elements as well as over-all cycles.

In addition, Abruzzi has introduced a new criterion of stability, the mean square successive difference ratio test.

Significantly small ratios indicate that successive observations are positively correlated; significantly large values indicate that successive observations are negatively correlated. Thus this statistic becomes valuable to detect any trends in the data. The same methods used to determine local stability were in turn used to detect grand stability, except that in this case the collection of data took place in very much the same manner that data collection for ratio delay studies takes place. Random readings in continuous series of five items were taken. They were distributed during the four basic work periods of the day. Again, these tests disclosed the existence of grand statistical stability.

$$\frac{\delta^2}{s^2} \qquad \frac{\sum^{N-1} (x_{i+1} - x_i)^2/(N-1)}{\sum_{i=1} (x_i - \bar{x})^2/(N-1)}$$

where x_i = any reading ($i = 1,2, \cdots, N$)

N = number of observations

The disclosure of the existence of this grand stability does prove that scientific time study is possible. That is, time study which is performed in accordance with the requirements of sound statistical inference. However, what remains to be disclosed is whether or not the limits of variation for both means and ranges are so wide that the results are of little economic significance for setting production standards. Abruzzi concludes from his findings that control charts with 3 sigma limits for groups of workers show equal degrees of variability even though they show widely different mean unit rates of productivity. The most important finding, however, is that local stability does not necessarily imply the existence of grand stability. They are two independent entities.

Inasmuch as trade unions are interested in the long-term characteristics of earning opportunities, it follows at once that they are much more interested in the conclusions derived from grand stability rather than from local stability. This, of course, means a change in the conventional method of collecting time study data. Where before a continuous short-run study was considered adequate, now small runs of five readings taken at random intervals over an adequate period yield more adequate data.

Superficially, it would seem that the trade unionist should be alarmed at Abruzzi's conclusion that time study is scientific. However, strangely enough, the very establishment of scientific validity for time study confirms the necessity for collective bargaining over production standards. The reason is that the economic requirements imposed upon the technique by collective bargaining would call for maximum confidence intervals of plus or minus 2½ per cent. Abruzzi's data indicate confidence intervals exceeding 2½ per cent many times. Under the circumstances, the time study can be used only to bring

the range of bargaining within rational limits. For example: Let us assume that a collective agreement calls for the continuous setting of piece rates. The basis upon which these piece rates are set is to yield an average hourly earning opportunity of $1.00. Let us assume further that the confidence intervals of the time study are a plus or minus 15 per cent. A 10 per cent increase in the earning opportunity is then negotiated. This means that the worker should be able to earn $1.10 per hour. The same time study man can come up with a scientifically derived production standard that will yield an average hourly earning opportunity of 95 cents per hour. In other words, not only would the worker not enjoy an increase, but he might well suffer a cut.

6. THE PROBLEM OF STANDARD DATA AND COLLECTIVE BARGAINING

The significance of this philosophy of time study is at once applicable to the trade unionist's attitude toward standard data.

Systems of standard data fall roughly into two classes: the macroscopic and microscopic. The macroscopic school of standard data calls for the formulation of data in terms of sizable job elements that reappear in many operations. The microscopic school formulates its data in terms of minute muscular reactions or therbligs or motion times.

In his study, Abruzzi examines both the macroscopic and the microscopic systems. Abruzzi's principal contribution to this field arises from his examination of what constitutes a logical subdivision of a total work cycle into elements. His statistical analysis was designed to determine whether or not the usual subdivisions of cycles from the most macroscopic to the most microscopic are statistically independent if they are to be used as an additive set —that is, if they are to carry a time assignment independent of the element that precedes or follows the element being measured If statistical independence cannot be established for these elements, then a minimum condition for their use must be at least a constant relationship or correlation. By the use of rather complex statistical multivariate analysis techniques, Abruzzi found that for some specific operations the nature of the relationship among macroscopic elements, let alone microscopic elements, was so complex that it varied from operator to operator. In fact, at times it varied at different times for the same operator. This is hardly the sort of foundation upon which objective systems of microscopic data can be built. These conclusions would tend to substantiate the findings of the Gestalt psychologist and industrial engineers like Gillespie and Mundel: "The whole is different from the sum of its parts."

Gerald Nadler has conducted an experimental investigation into the fundamental assumptions behind systems like methods time measurement, motion time analysis, and work factor analysis. Nadler gives the fundamental assumption behind all these systems. They are:

> 1. All types of activity can be divided into qualitative basic units of work.
> 2. To each basic qualitative unit of work a universal time value can be assigned for rate setting purposes.*

In testing the validity of this second assumption, Nadler observes that all predetermined time systems would have assigned the same value to a therblig transport empty which was performed under seven different conditions. Yet there was a significant difference of 16 per cent in the time required to achieve this transport empty under seven different conditions which he lists. After listing a number of such cases he concludes:

> The problems of first defining all types of relationships and secondly ascertaining consistent applications of these definitions seem virtually insurmountable

* G. Nadler, "Critical Analysis of Predetermined Motion Time Systems," *Proceedings of the National Time and Motion Study and Management Clinic*, 1952, 2.

even from relatively simple activities and relationships.*

Furthermore, he goes on to state that all the basic data in these systems depend upon rating. As he puts it:

> Even if we had an accurate system of rating, what to rate is not known, universal times for basic motions do not seem to be feasible, warranted or sufficiently accurate.†

Nadler then proceeds to prove that the application of each system is inconsistent within itself from job to job.

He then refers to studies at Northwestern University in which very large variations in results have been demonstrated from one system to another for identical activities. These variations were confirmed by the Research Institute for production engineering in Norway.

The most widely publicized of these systems is Method-Time Measurement. The writer evaluated this system in a review of the book *Methods-Time Measurement* by Maynard, Stegemerten, and Schwab. At that time, he paid special attention to the one demonstration of validity that appeared in the volume. He wrote:

> The authors attempt to validate their system by comparing the results of twenty-seven time studies by the leveling method with the results obtained by methods time measurement for the same twenty-seven different operations.‡

The authors then conclude:

> The total time allowed by time study was 3.4615 minutes. The total time allowed by methods time measurement procedure was 3.4414 minutes. This is a difference of less than six tenths of one percent.**

In as much as both sets of figures include leveled data, it is not clear exactly what this is supposed to prove. Then again, individual differences for the 27 operations should have been paired and their deviations squared and totaled. Totaling respective times and comparing over-all totals is misleading, because positive and negative errors cancel each other out. This fact leads to attributing a much closer correlation to the data than actually exists.

		Leveled time (dec. min.)	
Part No.	*Dept.*	*Time study*	*Methods-time data*
E21879	Forming	.0810	.0828
E9113	Forming	.0950	.0887
E26312	Forming	.0461	.0422
E17780	Forming	.0428	.0400
E2518	Forming	.3474	.3504
E24060	Forming	.0330	.0336
E25837	Switch	.0954	.0942
E2486	Sundries	.1800	.1788
6174	42	.1452	.1452
6197	42	.1260	.1320
5612	Switch	.1210	.1220
6208	43	.6798	.6780
E24769	Forming	.0640	.0640
E4646	Forming	.0570	.0570
E25921	Receptacle	.1080	.1086
C2040	Switch	.1680	.1740
C10	Switch	.0588	.0594
87145	43	.1260	.1200
73752	Sundries	.1247	.1135
Cat. F56	Switch	.1420	.1432
F6233	Switch	.1060	.1056
E25993	Switch	.1260	.1218
FS5	Switch	.0730	.0733
E3854	Forming	.0680	.0620
E24060	Forming	.0330	.0330
E23965	Forming	.0343	.0381
E20486	Forming	.1800	.1800

By permission from *Methods-Time Measurement* by Harold B. Maynard, G. J. Stegemerten, and John L. Schwab. Copyright, 1948. McGraw-Hill Book Company, Inc., p. 132.

A widely publicized paper by K. C. White of the Cornell Sibley School of Mechanical Engineering delivered before the 1950 annual meeting of the American Society of Mechanical Engineers has been used to confirm the usefulness of methods time measurement. Professor White concluded from his examination of methods time measurement that:

* *Ibid.*, p. 3.

† *Ibid.*

‡ In *Industrial Labor Relations Review*, Cornell University, Vol. 2, No. 3, April 1949, 456-458.

** Maynard, Stegemerten, and Schwab, *Methods-Time Measurement*.

> The data collected so far appears to point toward the practicability of defining work elements in terms of fundamental elements of motion common to a wide range of industrial activity and the establishment of times for these elements. . . . In summary the check studies have consistently ranged within approximately plus or minus one per cent of the MTM times. For individual elements time differences between check times and MTM times in the order of 0.1 to 0.5 TMU's (.00006 to .0003) minutes are not uncommon and, as evidenced in this paper a few are larger. . . . No reason is now apparent why continued study should not result in reconciling the differences that do exist.*

Both Mundel and Nadler have questioned the validity of the White Study. Nadler states:

> This Cornell University work arrived at the conclusion that the systems can work and that the data of the system studied are essentially accurate. However, there seems to be a lack of correlation between the facts presented in the report and the conclusions drawn.
>
> (a) The Cornell University researchers admit that levelling or rating is not accurate. One conclusion states that "since a single level of performance is represented," the standards are consistent. Where did such a single level of performance come from when the rating procedure is not accurate?
>
> (b) The study adds up the check study values for given motions and adds up the same motion values from the procedure under study. The difference of totals is 0.9%. This is somewhat misleading. Why not add a few more values to both sides? The percentage difference will be decreased because the calculations will deal with a larger number in the denominator.
>
> The true percentage differences are obtained by subtracting one value from the other for a given motion, converting this subtraction to a percent by dividing by one of the values and then calculating the variability based on these percents from all of the motions.
>
> (c) The report states that there is 7½% error 75% of the time in the standards set or, turning it around, there is *more* than 7½% error 25% of the time, and yet the conclusion states that standards set by the system are accurate. At this point the Cornell University work substantiates the conclusions of this paper. The variability of the check study time values was almost exactly the same as that calculated by our studies.
>
> (d) Another statement mentions that the "check studies have consistently ranged within approximately plus and minus 1%" of the predetermined motion time stem being checked. However, the data in the back of the report which was presented for the simplest of all activities, transport empty and transport loaded, show that only 20% of the values are within 1%. Actually, there was a difference from the studied system's values of greater than 4.6% to 6.7% one third of the time. This error of non-reproducibility of time values supports the conclusions of the research and analysis work presented in this paper.
>
> (e) Another statement in the report indicates that although there were some high errors, these would be eliminated by combination with other motions. As indicated before this is not the case. The concept referred to here is well known to those familiar with statistical quality control, in relation to combination of tolerances in assembly work.
>
> (f) A statement is made that context therbligs have some effect on times but that context can be taken care of by the addition of a new motion. This could possibly be true, but how could this be done in view of the results of the work which was done for the Navy and the experiments which were done at Washington University?
>
> (g) Tables are presented giving the levelling factor and the time for each distance of movement. The levelling factor has correlation of .98 with the distance traveled. This is rather exceptional, since research work has shown the pace or levelling factor should have no relationship to distance.*

This controversy over the validity of standard data was brought to a head at a general conference on Methods of

* K. C. White, "Predetermined Elemental Motion Times" Paper No. 50-A-88 presented at the 1950 Annual Meeting, The American Society of Mechanical Engineers, p. 10.

* Nadler, "Critical Analysis of Predetermined Motion Time Systems," 28

Establishing Motion Time Data called by the American Standards Association January 23, 1953. The conference was initiated as a result of a letter sent to the American Standards Association by Mr. H. B. Maynard on behalf of the Methods-Time Measurement Association. Pertinent abstracts follow.

> . . . I am writing to you formally to request the American Standards Association to initiate a project designed to establish standards in the field of predetermined motion times.
>
> At the present time, there are several systems which use predetermined motion time standards, the best known of which is probably the methods-time measurement procedure. This procedure was fully described in a book published in 1948 entitled *Methods-Time Measurement* by Maynard, Stegemerten, and Schwab.
>
> The MTM Association since its inception has urged that the proponents of all systems of predetermined motion time standards get together and develop one set of universally acceptable standards.

In attendance at the conference were representatives of organized labor, the technical societies, and trade associations. The current attitudes of organized labor toward these techniques is perhaps best understood by extracts from the stenotyped manuscript that summarize the conference proceedings.

Mr. Stegemerten, one of the founders of the MTM system said that:

> The Society for the Advancement of Management had appointed a committee for the purpose of standardizing and bringing about uniformity in the rating of performances of operators being studied, with a view to determining a time standard for the performance of operations. Mr. Maynard and Mr. Stegemerten had been members of the SAM committee. Their work on this committee had led to the idea of setting up a set of predetermined time standards as further developed in the book on Methods-Time Measurement.

Mr. Stegemerten further stated:

> The area of greatest controversy in setting standards of this kind had been in the rating of performances, and it had been felt that with a procedure such as the proposed predetermined motion-time data, this area of controversy would be eliminated.
>
> After the approach to the problem, as now sponsored by the MTM Association, had been announced, there had been introduced a number of other approaches which more or less deviated from the original MTM System. In the opinion of the MTM Association, its purpose would be defeated if such disagreement between systems continued. Therefore, the MTM Association had developed the idea that it would be well if all those interested in furthering the scientific approach to the establishment of work standards could agree on a single approach based on a unified standard procedure for predetermining operation times.

Mr. Winslow, an officer of the MTM Association, remarked that:

> There were thousands of engineers today who had been trained in the use of predetermined times. Great value could be obtained from the various systems in use. Many of these . . . were not even known to him, but their authors certainly should be invited to make a contribution to the general project.

The American Federation of Labor representative stated that:

> The AFL's position was that the ASA should not concern itself with this field because there was nothing to standardize as yet.

He added that:

> He did believe that the labor movement and the engineers should get together under their own auspices and hammer these things out. In fact, he had made a suggestion to this effect when the SAM rating film was first publicized, but the opportunity was never accepted. This was when labor wanted to question the value of the rating films developed by the SAM. He believed that these matters should first be straightened out within the societies engaged in research in this field before the problem was brought up before the ASA in an effort to set up an American Standard.

Mr. Weinberg, the representative of the CIO, stated that:

. . . Mr. Winslow had repeatedly stated that there were thousands and thousands of engineers and hundreds of companies using the proposed system. Well, there were thousands and perhaps millions of people selling patent medicines of all kinds and the question arose whether the ASA would be operating in its proper sphere if it attempted to standardize the terminology of the bottles these people tried to sell to the public. Also, there were thousands of astrologists, who, using different systems, came forth with different results, and there were people inventing machines for perpetual motion. Did this mean that there should be standards in the field of astrology and for the development of perpetual motion machines? Before any attempt was made to develop standards in the field of motion study, it seemed to me that an investigation should be made whether there was anything worthy to attempt to standardize. In this respect, those present might become acquainted with the work done by Dr. Abruzzi and Dr. Davidson.

.

Dr. Davidson said he was present in a dual capacity. In representing Ohio State University, he was supposed to be one of the academicians. However, he also represented the American Institute of Industrial Engineers, a professional organization of individuals having the responsibility for choosing the methods they will use, in the same way as a doctor will do this.

Dr. Davidson then added:

. . . A pertinent question was what was meant by a "standard"? He said there were things that might be called "natural standards," such as physical constants. These could be determined by scientific methods. Perhaps the approach to motion-time standards was predicated on the assumption that there was such a thing as a basic, fundamental motion. However, he believed that in the opinion of industrial and experimental psychologists, there was so far no evidence that there existed any fundamental basic motion. Therefore, the classification should be regarded as an arbitrary one. As long as people agreed as to what the term meant, they could communicate but the term should not be regarded as defining a fundamental thing.

It appeared that the ASA should concern itself with standards that might be called "arbitrary" standard: these were set up on the basis of a consensus of all people interested and were desirable. Such arbitrary standards had been established where there was no natural standard, and where it was impossible to apply scientific methods. Therefore, Dr. Davidson felt that some of those present who had spoken earlier, had not expressed themselves correctly when they described their system as a scientific approach. Rather, the methods under discussion were used because there was no scientific approach. It was a pragmatic approach.

The AFL representative then challenged:

It might be well to state plainly the question: "Why do you want an American Standard?" Could the reason possibly be that it became embarrassing when a trade unionist declared that all of the proponents of systems had different situations, and all of them gave the wrong answers? If all proponents could get together and give the trade unions one answer, this would make it easier for the proponents. [The implication was that it sounded like a meeting to propose the ground rules for a conspiracy to conceal valid scientific differences from the public.]

The conferees finally voted 16 to 3 to reject any American Standards Association project at this time in the field of predetermined motion time.

What does this add up to in terms of union policy when a union officer is confronted by these predetermined motion time systems? The trade union point of view was summarized in this writer's address at the University of California, to which previous reference has been made:

Does this mean that trade unions will reject all systems of standard data out of hand? Not at all. We are willing to recognize that they are a rather poor empirical attempt to develop a modus

vivendi upon which both management and labor can reach agreement. However, under no circumstances would we permit ourselves to be bound solely by the technology of these systems in dispute cases. They at best stabilize a human relationship. They are useful provided we recognize that the failure to achieve a rate developed under standard data does not indict the worker; the rate may very well point up the limitations of the technique.

7. THE TREATMENT OF WAGE INCENTIVE PAYMENT PLANS

The same University of Chicago conference of union technicians to which we have already made reference commented on various wage incentive payment plans. The report of the conference gave a brief classification of existing plans, followed by a discussion of existing trade union attitudes. The discussion follows.

Discussion of Wage Incentive Payment Plans

The conferees were unanimous in agreeing that the increasing automaticity of many industrial operations in which workers have become mere lever-shifters raises the whole question of how important the problem of wage incentive payment plans will continue to be. Much more fundamental than this question is the problem of relative employment security and the means of distributing the increment of increased productivity to those lever-shifters who seldom control the speed of production. Wage incentive payment plans were developed during the period when the overwhelming number of industrial operations were dependent on the physical exertion of the worker. The evolving technology of American industry may very well change the relative importance of wage incentive payment plans in the future and the resultant emphasis placed upon them by trade unions. A tendency is seen in that direction in the emphasis developing over the annual wage.

Many of the conferees objected to wage incentive payment plans on principle. They wanted no part of them. The plans were an endless source of grievances and made the administration of a collective agreement immeasurably difficult. In addition, they felt that the wage incentive payment plans were nothing else but a device for shifting many of the management risks to the shoulders of the workers. This was the position of the Auto Workers.

Others felt that wage incentive payment plans had become so integral a part of the wage payment structure of the particular industry in which they operated that any attempt by the union to oust the plan would be frustrated. They were primarily interested in developing safeguards that would protect the workers' standards in the operation of these plans.

Still another group actively advocates these plans. They claim that the plans solve certain problems for the union. These problems generally arise when employers complain that variation in the productivity of workers puts them at a competitive disadvantage in comparative direct labor costs. The wage incentive payment plan always pinpoints this direct labor cost. In addition, the variability of the operation of these plans has served as a means of securing increases that were otherwise impossible.

A fundamental change in the approach to wage incentive payment plans was advocated by some of the members of these latter two groups. Objection was taken to the very term "wage incentive payment plan." The implication is that the worker is actually entitled as a matter of right to a fundamental wage payment only: the day rate or the base rate, as it is called in the incentive wage payment plan. The understanding is that as a reward, not as a right, a worker will be paid an additional bonus for additional effort. A much healthier approach to this problem would be to change the name of this method of wage payment to something like "productivity wages." The understanding is that a contract is entered into between the management and the

workers establishing management obligations to furnish the opportunity for the workers to make a specified hourly wage at a normal working pace. The worker in turn obligates himself to meet the production standard that is jointly set.

The results of this reasoning can be readily seen. If there is a management breakdown in either production control or a machine, daily workers are not paid in terms of an artificially deflated base rate, but at the average hourly rate which they have demonstrated they are capable of earning. The argument that payment at such a rate abolishes the worker incentive becomes untenable. It might as well be argued that this obligation on the part of management to pay the average hourly rate is an incentive to see that its factory management is operating properly. Most engineering consultants in any case have adopted this method of payment for idle time under pressure from the unions.

The principal administrative problem that continues to bedevil the operation of these plans according to most of the conferees continues to be exactly what is meant by the phrase, "The rate remains unchanged unless the method is changed." The practices of some firms have led to a suspicion of the techniques of work simplification.

Misgivings were expressed that the techniques of motion study were sometimes abused to simulate a new motion pattern for an old operation in order to justify the setting of a new production rate. This would generally take place on an operation on which the management had committed itself that no cuts would take place as long as the method remained unchanged. The management would seek out those operations which it defined as loose and by redefining the motion pattern would attempt to justify a much tighter rate.

This abuse was particularly found in the auto industry. The UAW now insists upon a detailed elemental breakdown of the before and after operation, with the time-saving specified for each element in an attempt to control this abuse.

Still another abuse that arises in the installation of wage incentive payment plans is the attempt to apply them to operations that are fundamentally machine-paced. In this case again, production variation may be subject to a whole host of variables so numerous that they are uncontrollable. A good example is found in textiles, where the weather determines the number of thread breaks an operator will be called upon to repair. Under such circumstances, more often than not, the wage incentive payment plan is a device for shifting a management risk from the management group to the working force.

The third group, which actively advocated wage incentive payment plans, found that the plans were an invaluable device for stabilizing highly competitive industries. The union had a means of determining whether or not it was carrying free riders if an employer threatened to close down his plan because his labor costs were non-competitive. It served as an invaluable aid in establishing a nation-wide bargaining policy.

Sol Barkin, Director of the Textile Workers' Union of America, CIO, has added some objections of his own to wage incentive payment plans. He states: "Employers have offered many devices to circumvent the full impact of a wage increase by crediting part or all of the incentive earnings against such adjustments." The following is a summary of several devices that Barkin lists:

1. A proposal to institute an incentive wage system as an alternative to a wage increase.

2. A proposal that wage increase be made not as additions to the base rates, but as supplements to current incentive earnings on a day-work basis. This practice has now become so widespread that in many industries these additions amount to as much as 50 or a higher per cent of the base rates themselves. This practice, of course, undermines the entire wage incentive system.

3. A proposal that wage increase be applied to the incentive earnings. The base rates under such circumstances would be raised only enough to main-

tain the existing relationship between incentive earnings and the base rates.

4. A proposal that the increase in base rates should be limited to an amount necessary to produce an increase in incentive earnings equal to the rise in the hourly rates.

5. A proposal that incentive earnings be increased by varying amounts to reduce the premium on incentive jobs where it is higher than the company's evaluation of proper job relationship for these jobs would indicate is desirable.

6. A proposal to scrap the incentive plan in order to tighten up procedures, restudy all standards, and eliminate all of the "looseness" of rates and methods which had crept in during the war period.*

The clash between management and union thinking in the installation and administration of wage incentive payment plans is perhaps best brought out in the Stolper Steel Case, as, incidentally, are the attitudes of the unions toward the professional engineers. At that time (1950) the writer addressed the following letter to his professional colleagues:

A situation has arisen in the state of Wisconsin which threatens to destroy all of the progress made in the past few years in reaching an understanding between the professional industrial engineers and the organized labor movement.

The matter involves the Steel Manufacturing Company, the International Union, United Automobile Workers of America, AFL, with whom the company has a collective agreement, and the Wisconsin State Labor Relations Board created by state statute.

The International Union, United Automobile Workers of America, AFL, has been one of the leading labor unions in adapting its collective bargaining practices to modern industrial engineering techniques. Some time ago their entire General Executive Board attended classes for eight hours a day for one whole week, under the direction of Hy Fish of the Roosevelt College Faculty, to familiarize themselves with job evaluation, time study and the design and administration of wage incentive payment plans. Their international representatives have had similar training. Other unions are hardly encouraged to follow suit by what has happened in the Stolper case.

Briefly, the facts of the case are as follows. On the fifth day of August, 1948, the Stolper Manufacturing Company and the Union executed an agreement. Section 12 of this agreement set up a wage incentive payment plan. The agreement provided that this section go into effect April 15, 1948 and continue until October 14, 1948. It was to renew itself automatically for periods of six months unless notice was given by either party in writing at least sixty days prior to any six months' expiration date.

Under this agreement, production climbed to anywhere from 120% to 131% of standard. It seems to have been higher in the early days of the agreement (around 131.3%) and fell off to around 121.7% on February 6, 1949.

As a result of dissatisfaction with the operation of the plan, the Union gave proper notice and terminated the agreement as of October 14, 1948. The company nevertheless unilaterally announced that it was continuing the wage incentive payment plan. Production, beginning February 13, 1949, fell to 100.3% and then varied between that percent and 104.0%. The men said in effect that they would give a fair day's work for a fair day's pay; they were not interested in the incentive increment; they wished neither to exert extra effort nor to receive extra pay.

The Wisconsin State Labor Relations Board has denounced this action as interference with production and as a slow down, and has ordered the Union to restore the "incentive level" of production. In other words, because the men had demonstrated that on a voluntary basis it was possible to reach 125% of a fair day's work, the Board has in effect ruled that this now becomes an obligation on the part of the men. Naturally, the labor member of the Board dissented and pointed out that even if the company were to discontinue paying the premium for extra effort, the union then would still be obligated to produce at 125% of a fair day's work.

If this ruling should be permitted to stand, then those of us who are industrial engineers identified with the labor

* Sol Barkin, "Labor's Attitude Toward Wage Incentive Plans," *Cornell Industrial & Labor Relations Review*, Vol. 1, No. 4, July, 1948, 565.

movement would have no other recourse than to recommend to all labor unions in the State of Wisconsin, or for that matter to any labor union operating in any state with a similar law, that they discontinue all wage incentive payment plans in their contracts and adhere strictly to the time work method of wage payment. Furthermore, we would be obligated to warn these unions that they must limit their cooperation with the employers in raising the level of productivity. This raised production level, which comes as the result of cooperation, would then become an obligation on the part of the men to which they would have to adhere, irrespective of any change in the attitude of the company or method of payment.

I believe that you will agree with me that such a course of action would destroy everything that has been done in the last few years to bring the trade unionist and the industrial engineer to a mutual understanding. It seems to me, under the circumstances, that a movement ought to be initiated by concerned organizations such as the Management Division of the American Society of Mechanical Engineers, the Society for Advancement of Management, and the Industrial Management Society of Chicago, with the following purposes:

1. To investigate completely the facts in the case outlined above;
2. If it is determined that these facts are such as to threaten the effective application of sound engineering practices in a collective bargaining situation, to stand ready to file supplementary briefs as expert friends of the court in the litigation that is to follow the determination made by the Wisconsin State Labor Relations Board.

May I hear from you on this matter?

The basis for a satisfactory relationship between labor and management in the administration of wage incentive payment plans or, as the Europeans refer to them—"Plans of Payment by Results"—has been developed by the International Labor Organization.

The International Labor Organization called together a meeting of experts on payment by results from the different countries making up the body. They drew up a set of general principles concerning the use of this system. The 1952 conference on increasing industrial productivity thought so well of these recommendations that they appended the conclusions of the group to their own report. Rudy Faupl of the American Federation of Labor and Mr. John C. Gebhart of the National Association of Manufacturers, both delegates to the conference, joined in signing the report. The 42 conclusions are of importance; recommendations 28 and 29 are of particular interest and are herewith reproduced:

> 28. No system of payment by results can be applied successfully if good relations do not exist between the management and the workers concerned. Before attempting to introduce any such system, therefore, steps should be taken to establish such relations and to obtain the consent of the workers concerned. It is advisable in this connection for the workers to be taken into the confidence of the management from the outset and for all features of the proposed scheme to be carefully explained to them in advance.
>
> 29. Provision should be made for the participation of workers' representatives in the introduction of the system in a manner to be defined by collective agreement. Such participation may take the form of participation in the timing of jobs, in fixing production standards and in setting rates; or it may take the form of participation in the establishment of appropriate safeguards.*

8. UNION ADMINISTRATION FOR HANDLING UNION PROBLEMS

Many unions have created separate staffs to handle production standards problems as they arise. The International Ladies' Garment Workers' Union was the first labor organization to create a separate Management Engineering Department for this purpose. The United Auto Workers, CIO, and

* *Practical Methods of Increasing Productibility in Manufacturing Industries, Geneva, 1953.* Conclusions of a Meeting of Experts at the 36th Sessio;

the Textile Workers' Union of America, CIO, soon followed suit. Other organizations, such as the United Rubber Workers, CIO, and the International Association of Machinists, AFL, retain specialists in these techniques on their national and regional staffs. Smaller unions have called upon the specialists on the staff of the larger unions for special consultation.

The International Ladies' Garment Workers' Union, AFL, has detailed the functions of its engineering department in the short statement that follows:

> The Management Engineering Department of the International Ladies' Garment Workers' Union was created by the General Executive Board, July 22, 1941. Its objectives were listed as follows:
>
> 1. To assist in improving the manufacturing techniques and operating methods of all branches of the ladies' garment industry with which the earnings of our workers are intimately bound up. This will be done through plant inspections by department representatives, followed by specific recommendations.
> 2. To serve as a central information agency:
>   (a) for the determination of the level of "fair piece rates."
>   (b) to record the production system and manufacturing techniques under which these rates are paid.
>   (c) to assist in training shop members and committees in distinguishing bad time study practice from good time study practice, in the determination of rates.
>
> Thus the Department serves both a policing and a cooperative function. However, the two purposes overlap and are not in distinctly different categories. Practically the entire women's clothing industry pays its wages on a productivity basis. That is, workers are compensated in accordance with their relative productivity. The plans vary widely but the predominant plan is ordinary piece work.
>
> The function of the Department is to serve as consultants to the officers charged with the negotiation and administration of the actual collective agreements. During the negotiating sessions advice is given to line officers about the effect of the design of the wage incentive payment plan in use in the factory on the earnings of the workers. In addition, the production standards underlying the wage incentive payment plan are evaluated.
>
> During the administration of the agreement the Department is consulted when new rates are set on new items scheduled for manufacture.

The technical services of the Textile Workers' Union of America, along with the qualifications of the personnel that are required for its successful operation, have been described by Solomon Barkin, Director of the Research Department:

> In response to general developments, and to those peculiar to the textile industry, the writer organized a technical service in the Research Department of the Textile Workers' Union of America. A specialized staff was, after some years, recruited to aid him in extending the service, and it now consists of a senior and junior engineer in the national office and two field engineers.
>
> Before describing the goals and the functions of this group, two conclusions reached early with regard to the organization of the service should be noted. First, the staff must consist of permanent personnel and not of consultants. There are practically no engineering consultants who could maintain an undivided loyalty to the trade union. They have been trained in management's approaches and techniques and depend upon management for their work. Few are prepared to serve trade unions without considerable re-education. They have no initial preparation for helping workers to protect themselves against management's authority. They are neither steeped in nor have had access to a comprehensive statement of labor's attitude towards these problems. To gain the necessary insight and understanding, and to learn how to adapt their professional engineering skills and knowledge to serve the labor movement, they must be given careful direction and enjoy an intimate and permanent relation with the trade unions.
>
> The primary function of the technical service of the Textile Workers' Union is to aid and train the Union's administrative personnel in the handling of prob-

lems of an industrial engineering character. The ultimate aim is to provide such training by demonstration and instruction as will make these officials self-reliant. They will then be able to understand fully the employers' proposals and their implications and will be acquainted with the methods by which they have been derived. After identifying the appropriate Union policy, which is seldom available in precise written form, they must be able to apply it in such a manner that it takes into account the local bargaining relationships and the long-term union and worker interests.

The above goal is constantly held to the fore. It means that the technical staff must remain small and place its emphasis on training. It also reflects the fact that, no matter how rational the argument and how complete and overwhelming the data, the final result in the vast number of cases will depend upon the balance of bargaining power. The Union's administrative personnel represent and direct its bargaining force and must therefore be the spokesmen in such negotiations.*

The United Automobile Workers' Union, CIO, has detailed the methods of operation of its own engineering department in a time study manual. The functions of the Engineering Division are as follows:

1. To provide local unions, through their Regional Offices or International Union Departments, with technical assistance in disputes about production standards, incentive rates, incentive plans and job evaluation plans.
2. To act as a general information agency for the Union on matters involving time study, job evaluation, etc.
3. When requested by the Regional Office, to give assistance to local unions in contract negotiations so as to ensure acceptable settlement of issues involving time study, production standards, piece rates and job evaluation and adequate contractual provisions for settlement of disputes over such issues through collective bargaining.

* S. Barkin, "The Technical Engineering Service of an American Trade Union," *International Labor Review,* International Labor Office, Vol. LXI, No. 6, June 1950, 11-14.

4. At the request of the Education Department, to conduct time study classes so that union members and representatives will thoroughly understand what the company time study man does, why he does it and where he is most likely to make errors in method or judgment, so that local unions will be in a better position to protect their members.

The Engineering Division, of necessity, has a small staff. However, this staff will be most effective and its services will be made available as far as possible if the procedure outlined below is carefully followed:

1. When a local union has a problem concerning time study, production standards, incentive plans or rates, job evaluation, etc., the services of the Engineering Division of the Research and Engineering Department can be obtained provided that the local union has made no commitment to the company regarding the procedure which the representative of the Research and Engineering Department will use.
2. The local union must first request the assistance of the Regional Office in settling the dispute.
3. If the Regional Office cannot effect a settlement of the dispute, the Regional Director will fill out and sign a "Request for Service" form and send it, with any other information he has, to the Research and Engineering Department of the International Union. It is the responsibility of the Regional Office to clear the matter through the proper International Department where the dispute is in a plant covered by a multi-plant Corporation Contract
4. The Research and Engineering Department will, without delay, notify the Regional Director, International Union Department, if any is involved, and the local union which of its staff members has been assigned to the case, and the date he will be available.

If this procedure is carefully followed, the Engineering Division will be able to give maximum assistance in reaching a satisfactory settlement. It must be emphasized, however, that under no circumstances should any local union, by agreement with management, commit a representative of the Research and En-

gineering Department to follow any specific procedure without first having obtained the written consent of the department.*

The approach to the actual operating methods that the trade unions use in settling production standards disputes within a time study context can be studied from statements of their procedures and from specific cases which have arisen.

The United Auto Workers instructs its locals along the following lines:

How to Handle a Production Standard Dispute

The UAW-CIO rejects time study as a means of determining production standards even though management uses it for this purpose. The basis for the rejection has already been noted earlier, and is the ammunition which UAW-CIO members can use to protect themselves against speed-up and unreasonable production standards arising from time study.

The worker's first line of defense against unreasonable production standards is his union representative in the shop—the steward, a committeeman or an officer of the local union. Any grievance regarding production standards should start by having the appropriate representative of the union present it to the company. However, the union representative must start the grievance out on the right road. What he does in the first stage of a production standard dispute will determine to a great extent the effectiveness with which the union can help him to defend the workers he represents. The International Union, therefore, urges that representatives of the union in the shop should be thoroughly prepared when handling production standard disputes, and recommends the following steps as a general guide for stewards, committeemen and local union officers.

1. *Remember that the real issue in dispute is not the time study but the production standard. The time study only represents management's attempt to justify its production standard. Some time study man may have distorted and obscured the basic facts about how long it takes the worker to do a job by intruding his own personal judgments and a lot of complicated arithmetic. But the final result he produces is still just management's opinion. Since, as we have seen, there is no scientific and objective measure available, the answer to management's opinion must be the Union's opinion based on the knowledge and experience of the worker who actually has to do the job plus the informed judgment of his Union representatives. Wherever possible, try to settle the dispute on the basis of your best judgment of what is a reasonable production standard, without getting tied up in arguments about time study.*

2. Remember that a grievance regarding an unreasonable production standard must be begun in the same manner as any other grievance. A full investigation must be made, and all of the information about the disputed job must be gathered. Two umpire decisions under the General Motors Agreement (E-62 of 1947 and F-53 of 1949) have established the right of the union representative to demand from management, even where the agreement language is far from specific, all of the facts in management's possession bearing upon the dispute. After all of the available information has been obtained, the representatives of the local union should be prepared to bargain on the matter in dispute with the proper representatives of the company. There are four traps to watch for in bargaining on a production standard dispute:

(a) The company may argue that the dispute is not a bargainable matter, and may therefore propose that the local union get someone to time study the job so that a comparison can be made between a time study made by the union and the one made by the company. *NO LOCAL UNION SHOULD AGREE TO ANY PROCEDURE OF THIS KIND.*

* *UAW:CIO Looks at Time Study.* From the advance draft manuscript of proposed pamphlet, pp. 82-83.

It means acceptance of the principle of production standards based on time study.

(b) The company may propose that a joint time study be made, where a representative of the union and a representative of the company both time study the disputed job at the same time. A comparison is then made between these two time studies. *NO LOCAL UNION SHOULD EVER AGREE TO ANY SUCH PROPOSAL.* This also implies acceptance of time study as a proper method of setting production standards. The Research and Engineering Department is willing and ready to help every local union protect its members against unreasonably high production standards or unreasonably low incentive rates. But its ability to help will be severely limited if you commit it in advance to following any particular method, especially a method as inaccurate and unreliable as time study. Leave the representative of the International Union free to use whatever approach to your problem seems best based on his wide experience with similar situations.

(c) The company may propose that a third party be asked to time study the job, his determination to be accepted by both the company and the Union. *NO LOCAL UNION SHOULD AGREE TO ANY PROCEDURE OF THIS KIND.* Again, it involves accepting the principle of setting production standards through time study. The time study yardstick does not become more accurate because a third party uses it instead of management. Besides, the third parties available for this purpose are, almost without exception, management consultants whose judgment may be warped by their financial dependence on management.

(d) The company may propose that a representative of the International Union's Research and Engineering Department be asked to make a time study and set the standard, which commits the International Union in advance to the method to be followed. *NO LOCAL UNION SHOULD EVER AGREE TO SUCH A PROCEDURE.* This also implies acceptance of the principle that time study is a proper method of setting production standards. The International Union's engineers are at least as competent as any others in making time studies. But competence in applying a faulty technique does not make the technique itself any better. The defects inherent in time study mean that results reached by a Union time-study man, while free from pro-management prejudice, are subject to the same errors as a time study made by anyone else. (This does not mean that the International Union's representatives will never make a time study. But when they do time study a job they do so with full knowledge of the weaknesses of their results and only when they are convinced that it is an unavoidable step in the direction of resolving the dispute in the workers' best interests. When a UAW-CIO engineer makes a time study he does it as a frank and open compromise with principle dictated by the urgencies of a practical situation. It would be irresponsible, for example, to refuse to make a time study where refusal to make it would lead to a strike while making it would smooth the path toward an acceptable settlement of the dispute on a peaceful basis.) THE JUDGMENT AS TO WHETHER OR NOT TO MAKE A TIME STUDY, HOWEVER, MUST BE LEFT TO THE INTERNATIONAL UNION'S ENGINEER BASED ON HIS EXPERIENCE IN HANDLING SIMILAR DISPUTES.

(e) One further trap sometimes set by management might be mentioned here even though it does not relate directly to bargaining on a specific dispute. Management will sometimes offer to have its time study man "train" the union's time study stewards so that they will "understand" the procedure he uses. Sometimes management will offer to send the stewards to school to study time study at management's expense. *NO LOCAL UNION SHOULD EVER AGREE TO SUCH PROPOSALS.* The only schools available for this purpose are management oriented;

and no management time study man will try to give a union representative an honest understanding of the unavoidable errors and arbitrary, personal judgments with which time study is filled. If he did so, he would be promptly fired. The International Union, through cooperation between the Education Department and the Research and Engineering Department, conducts frequent time study classes at Union summer schools throughout the year. Local unions should see that officers who are faced with time study problems attend these classes. There they will learn the truth about time study, and the proper methods to be used in protecting their members against it.

All of the above management proposals are designed to completely avoid collective bargaining on production standard disputes, and to force the local union to accept and use time study as a means of determining production standards. *No local union should allow itself to be put in this position.* Here are the reasons why. It is management which says that it can establish reasonable production standards by time study. The union does not accept this claim, and therefore cannot be a party to resolving production standard disputes by using time study. Moreover, the fact that a company says that it or anyone else can set reasonable production standards by time study does not make it so. The union must in all cases demand that the company present unquestionable evidence across the bargaining table to prove that it can in reality do those things that it says it can do.

This means that, where it is not possible to resolve a dispute without getting involved in time study, the union should require the company to submit its time study to a complete and searching analysis, and to bargain collectively on the basis of all of the weaknesses shown in that time study, and all of the other facts of the dispute. The inaccuracies of time study, which have already been pointed out, indicate such a large margin of error as to make it completely unreliable as a means of resolving production standard disputes. *In almost every case the difference between the company and the union in a dispute is less than the margin of error involved in a time study.*

3. If, despite your best efforts, you have been unable to resolve the dispute without getting into the time study, it will become necessary to subject the time study to thorough and searching examination. Start right at the beginning. Carefully examine the company's detailed record of the job, taken from the time study man's work sheet. If the record does not contain sufficient information so that the job can be reproduced exactly as it was when the time study was made in terms of both the physical set-up of the job and the general working conditions, there is no way of checking whether the conditions on the job now are the same as they were when the time study was made. If that is the case, the company should be told that for that reason alone its time study is completely useless.

4. If the time study man's detailed record of the job contains sufficient information, compare it item for item with the methods and conditions under which the job is being done at the time of the dispute. Find out whether the job is being done in *exactly* the same way as it was when the time study was made. Here are a few reminders of items to be checked:

Is the material the same?

Is the material placed in the same location?

Is the material brought to the job in the same way?

Is the material removed from the job in the same way?

Is the machine operating in exactly the same way?

Are the same tools and fixtures being used?

Is the motion pattern of the worker the same?

Do the workers now doing the job have the same amount of training and experience as the worker who was time studied?

Note carefully any differences between

the details of the job as it was set up for the time study, and as it is being performed at the time of the dispute. These differences may require more time for the job. If so, they should be used in bargaining with the company to get more time.

Remember: One of the frequent inaccuracies of a time study arises when a job is not operating under exactly the same conditions and circumstances as those in effect when the time study was made. In addition it may be that the time study man's record of the job in dispute is incomplete or inaccurate. In either case there is no way to make the above check. However, an incomplete or inaccurate record would nullify the company's case, and substantiate the union's position that the disputed production standard is in error.

5. Read over the time study man's record of all the work elements very carefully to be sure that each one follows logically from the next one, and that the beginning and ending of each work element have been carefully defined. When the beginning and ending of each work element are not clearly defined, any attempt to establish a time value for its performance is nothing more than guesswork.

6. Check the time study man's description of each work element against the work which the worker on the job is actually performing. Make sure that no work has been left out. When work is being performed which is not recorded in the element breakdown, then such work should either be discontinued, or it should be included in the element breakdown and additional time allowed for it.

7. Check the time readings recorded by the time study man to be certain that the time study was made by continuous timing. This can be done by starting with the watch reading recorded for the first work element, and following each recorded time to be sure that each time value follows logically from the previous one.

Remember: If the time study was made by snap-back timing, there is no way of checking to make sure that the time study includes all the time that was actually spent by the worker in performing his job. You can be certain, however, that with snap-back timing the time study man was unable to record the time that was actually spent resetting his watch at the conclusion of each work element, so that the job will require more time than his time study record shows.

8. Be absolutely certain to check the arithmetic by which the time study man figured the time required for each work element from the successive watch readings.

9. Find out exactly how long the time study lasted, and at what time of day it was made. Then ask yourself these questions:

Was the time long enough to include everything that will face the worker in the performance of his job?

Was the time study an accurate sample of the day's work, or was it made during a part of the day when the worker was fresh and apt to be working faster than he would later on?

The company should be required to prove by sampling procedures and common sense that the sample it has is a proper one.

10. Find out what rating factor the time study man applied to the time actually taken by the worker he studied. Check to find out when the time study man recorded his "rating factor." It should have been recorded and shown to the worker being time studied and to his steward before the time study man left the job. Next compare the rating factor with what the worker believes is a proper pace. This can be done by watching the worker who was timed work at what he considers a proper work pace. Use your own best judgment to decide whether or not he is working at a reasonable pace. Then compare the amount he can produce in a given time with the company's production standard for the same length of time. For this purpose the clock on the wall will do. You don't need a stop watch because, as we have seen, nothing of

real value is gained by breaking the job down into parts. In this manner you can judge for yourself how far off the company's time study man actually is. Your judgment with regard to work pace is just as valid as that of the time study man. As in other questions that come up about time study, the combined judgment of everyone involved in a dispute will produce a much more equitable result than the judgment of the company's time study man alone.

11. Find out whether the time study man used all the element time values he measured. If he discarded any, make sure there is a clear explanation on the record of why they were not used. If he struck out any time values just because he considers them to be "abnormal," or by applying a mathematical formula, it is certain that the "representative times" he finally decided upon are nothing more than a guess. If specific reasons are given for striking out any values, decide whether the reasons are valid. Check with the worker on the reasons given by the time study man for his "strike outs."' Make sure the situations for which times were struck out do not include those that would recur on the job. Remember that minor variations in the motions used, or incidents such as a fumble or dropping a piece, are not valid reasons for striking out a time, because they do happen from time to time on any job. The worker is a human being, not a machine.

12. Check the "representative" element time values to be sure that only a simple average is used in calculating them.

13. Check to be sure that the percentage figure that is used to calculate the time for allowances for personal time and fatigue gives the worker the time to which he is entitled.

14. Make a final check of the time study man's arithmetic in all calculations.

If a grievance cannot be settled without getting into details of the time study, the union representative who carefully checks all the above points will be in a good position to defend the worker in bargaining with the company. Most disputes can be satisfactorily settled if the errors and evidence of bad judgment—and often bad faith—on the part of the time study man are clearly presented in the collective bargaining sessions with the company. If the company still will not agree to a settlement, a union representative may wish to make an independent check of the job to get more information. For example, the union might find it useful to establish the amount of time actually lost in a day due to delays on the job, and might even wish to check the actual cycle time of the job. This additional information should help the union to settle the dispute through collective bargaining. If a satisfactory settlement cannot be reached, the local union can decide whether to ask for help from the International Union.

THE BASIC THING TO REMEMBER AT ALL TIMES IS TO MAINTAIN FAITH IN YOUR OWN BEST JUDGMENT. IN THE LAST ANALYSIS, JUDGMENT IS THE BASIC AND DECISIVE ELEMENT IN THE TIME STUDY MAN'S CONCLUSIONS. YOUR JUDGMENT HAS JUST AS MUCH VALUE AS HIS.

The above is verbatim reproduction from an advance draft of the forthcoming pamphlet, *UAW:CIO Looks At Time Study*, United Auto Workers, CIO, Detroit, Michigan.

The United Automobile Workers, CIO, were originally denied any voice in the setting of production standards. For example, the Ford Agreement of September 4, 1950, provides (article 4, section 4) that the right of the company to establish and enforce production standards is recognized. On the other hand, article 7, section 18 (f) provides that failure to reach an agreement (over a production standard) the Union shall have the right to strike over such dispute. The impartial umpire who arbitrates disputes arising under the agreement is specifically excluded from this area. The union evidently finds this arrangement very much to its liking.

It had to take this arrangement originally because management maintained that the establishment and administration of production standards must remain non-arbitrable.

The union finds this freedom of action so attractive that it endured a long drawn-out strike against the International Harvester Corporation. The corporation wanted to eliminate the union's right to strike over production standards but was willing to make the settlement of production standards disputes arbitrable.

The final compromise was article 12 of the International Harvester-UAW agreement. This clause gives the union the choice between taking the production standard dispute to arbitration or using an alternative procedure, which follows: First, provision is made for joint study of the job by representatives of

FIG. 17.2 WORK DUTIES CHART.

TEXTILE WORKERS UNION OF AMERICA
Research Department
New York, New York

Research Form #1

WORK DUTIES CHART

OPENING & PICKING

This is a list of the EQUIPMENT and the DUTIES of the workers in connection with OPENING & PICKING. If there are any equipment or duties performed that are not listed, please add them. It is intended to cover all workers who spend all or part of their time around the OPENING and PICKING MACHINES. If the duties of some occasional workers are not listed, please add the duties and job title.

When this form is completed, it will show who performs EACH duty around the OPENING and PICKING MACHINES. If at present there is a temporary rearrangement of duties, or if there is more than one arrangement, please note each arrangement and when or where it is used. Use several charts if necessary to show the different arrangements of duties.

COMPANY ______________________ MILL ______________________

Filled out by: ______________________ Position ______________________
(Name)

Date ______________________ Chart No. ______________________

A. EQUIPMENT REPORT - OPENING ROOM

TYPE OF MACHINE	Manufacturer's Name & Machine Model No.	Check (x) Units That Have Automatic Lubrication	No. of Machines
1. Feeders:			
a. Automatic	______	______	______
b. Hopper	______	______	______
c. Blender	______	______	______
d. Fiber Meter			
(1) Single	______	______	______
(2) Multiple for blends	______	______	______
2. Bale breaker	______	______	______

the management and the union. If the union is still dissatisfied, the local union is free to take a strike vote.

A unique approach to collective bargaining problems on the job which links job analysis to the problem of work load measurement is being developed by Solomon Barkin, Research Director, Textile Workers' Union of America (CIO). Mr. Barkin describes his technique in the following way:

> The engineering profession has contributed several techniques for job analysis through the recording of job duties.
>
> These techniques began with crude job descriptions and element-listings. With the development of man-and-machine balancing techniques, process flow analysis, and motion study, engineers developed new types of charts and analytic forms. They increased the analyst's perception by requiring him to describe procedures in greater detail.
>
> The trade unionist has found these techniques most useful in defining the job duties and work assignments accompanying a wage bargain. He has insisted upon job specifications that outline what is expected of the worker for the agreed-upon rates of pay.
>
> In facing up to these demands, the TWUA Research Department found current techniques for job description to be inadequate. Existing techniques had not been adapted to the needs of the textile industry, where workers tend a battery of semi-automatic processing machines. A worker at such a machine is usually only one member of a group of attendants servicing it. The number of job classifications attending the machine may range from three to as many as 25, depending upon the degree of specialization prescribed by the management.
>
> The work-duties chart is a technique of job description which meets the peculiarities of textile jobs and serves collective bargaining. It has proved useful as an analytical tool for management. It is a standardized listing of the operating duties required to be performed, and, in fact, currently being performed around a particular textile machine. The charts are usable in all mills. The list is sufficiently complete so that few new duties have to be added in specific mill studies.
>
> The distinctive value of the chart is that it includes all duties of all employees servicing or tending the machine. Indirect and auxiliary duties often overlooked in individual job descriptions are itemized. By consulting the chart, the employee learns of his responsibilities as well as those of their workers in associated job classifications. The worker is made more certain of his own assignment. The chart tends to eliminate complaints which arise from workers who do work assigned to job classifications other than their own. It makes each worker's responsibility apparent to other workers.
>
> The chart has another special value for the trade unionist. It provides him with a standardized listing of duties likely to be found in a mill. It therefore eases the job of making his own studies. Instead of depending upon the worker's recollection of his duties, the union representative can obtain a complete listing of the duties of each job by having workers on each job classification check the listed duties they perform. He therefore can isolate uncertainties on job responsibilities and can clear them up as his first task in the analysis of complaints and grievances.
>
> Union representatives have also found these charts of value in making comparison of job assignments among mills. Knowing that job titles are not an adequate index of the precise duties performed by a worker, the union representative can use the chart as a ready method of ascertaining detailed job duties in and making comparisons between mills. By noting the difference in work duties, the union representative can make allowance for variations in the pattern of duties.
>
> The listing of duties in these charts is not as complete as would be required for the setting of production standards or incentive rates. Yet the functions covered are more inclusive, since great accent is placed upon the auxiliary and randomly occurring duties. For plants that prepare detailed analysis of work elements, this chart provides a ready summary which integrates the work of all persons tending a machine in a manner that clearly defines the scope of responsibilities of each worker.*

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* Solomon Barkin, *Work Duty Charts for Textile Operations*, A Research Department Technical Report, Textile Workers Union of America, CIO, 1951, pp. 1-4

Labor is not alone in finding that many of the administrative problems presented by these industrial engineering techniques sometime make the economics of their use highly suspect.

Professor Roy of Johns Hopkins was led by his experience in a number of arbitration cases to a pronounced disenchantment with individual wage incentive payment plans from management's point of view. He expresses his doubts in the following statements:

> There is a prevalent belief, particularly among industrial engineers that the sequence, *operation analysis-work measurement-incentive* yields a high wage-low cost result.
>
> It is held that hidden costs seldom are included in evaluation of incentive plans. On the contrary, plans are viewed in an aura of wishful thinking.

He then closes with this significant remark:

> It is difficult to say what may take the place of present incentive plans, but it does not appear unlikely that some means of securing cooperation in the manner revealed by the Hawthorne experiments may well be the direction taken.*

This turning to the techniques of industrial psychology, human relations, and communication led the writer to believe that trade union reactions to some comments on these techniques would be useful to industrial engineers.

9. INDUSTRIAL PSYCHOLOGY AND INDUSTRIAL RELATIONS

The techniques of industrial psychology, including the subsidiary fields of aptitude testing, human relations, and communications techniques, are not in the main stream of scientific management or industrial engineering. However, some of these techniques are so closely related to the work of the industrial engineer that they deserve some comment.

The earliest technique that would have appealed to Taylor is aptitude testing. It will be recalled that Taylor laid great emphasis on getting the right man for the job. The aptitude tester seeks to fill Taylor's request. The field of industrial psychology received its first systematic presentation by Dr. Hugo Munsterberg of Harvard University.*

However, Viteles was the first in our time to make a careful delineation of the field of industrial psychology. He quotes Munsterberg, first professor of Industrial Psychology in the United States at Harvard:

> He [Munsterberg] indicated that in industry the psychologist can serve, first, by finding the men whose mental qualities make them best fitted for the work which they have to do; secondly, by determining the psychological conditions under which the greatest and most satisfactory output can be obtained from every man; and, in the third place, by producing most completely the influences on human minds which are desired in the interest of business.†

Viteles' principal work was in the field of selection of streetcar motormen, telephone operators, and ship's officers.

A trade unionist's reaction to a straight program of aptitude testing was voiced by the writer at the September 1949 Denver meeting of the Industrial Relations Research Association and American Psychological Association.

> . . . What motivation is there for efficiency among workers? Viteles attempts to talk in terms of long-term economic considerations. Short-run low costs for the manufacturer may mean fewer jobs, more work and less pay. It is somewhat amusing to see the psychologist take the long-term point of view in considering the very people whom he is supposed to understand. An elemen-

* Robert H. Roy, "Do Wage Incentives Reduce Costs?" Vol. 5, No. 2, *Cornell Industrial and Labor Relations Review,* January 1952, 207-208.

* Hugo Munsterberg, *Psychology and Industrial Efficiency* (Boston: Houghton Mifflin Company, 1913).

† Morris S. Viteles, *Industrial Psychology* (New York: W. W. Norton & Company, Inc., 1932), p. 42.

tary axiom of psychology should be that people live in the short run, marry in the short run, bring up their children in the short run, and develop neuroses and psychoses under the stress of insecurity, all in the short run.

The function of the union is to preserve human values. It is the function of the union to ask pertinent questions. When new fuels, for example, are substituted for old fuels, does the added efficiency of the new fuel justify the creation of ghost mining towns and the leaving of people stranded without a means of livelihood?

It is difficult for unions to become enthusiastic about selection techniques in industry. Viteles is aware that many psychologists feel that they have an acceptable test with validity correlations of 0.4 and even lower. Unions do not look upon workers as abstract collectives. They are frankly concerned about the injustice to workers who may be falsely classified as incompetent, that is, they are unfortunate enough to fall into that 0.6 part of the correlation, remaining between 0.4 and perfect correlation. Might I add that the number of new workers taken on by the average firm is generally so small that even this correlation coefficient of 0.4 is meaningless because of the small size of the groups.

Yet the trade unions are invited to hitch their policies to this rickety device, all in the name of science. Naturally, if these tests are used to select new workers from the open market to whom the union has incurred no particular obligation, the company and the industrial psychologist are likely to be met with indifference rather than opposition. If, on the other hand, they are to be used as a determinant of in-plant promotions, then they will have to be a good deal more valid before the union will permit them to be the criterion of judgment of whether or not any particular worker is to be frustrated or permitted to go ahead.

What is so disturbing in Mr. Viteles' approach is the great emphasis placed upon psychology as a tool to select the proper worker for the job rather than upon the adaptation of job specifications to workers.

As an engineer I know that many technological changes in industry today are not motivated by increased physical productivity. They are motivated by the desire to utilize unskilled labor which may be purchased at a cheaper price than skilled labor because of our wage structure. An interesting experiment was conducted during the last war. Two factories manufacturing the same product were set up in two different ways. In one, the operations were reduced to their simplest repetitive components. In the other, enough different operations were made up into individual work assignments to sustain the interest of the worker. By all engineering assumptions, the former factory should have been more productive. The reverse turned out to be true.

Now, of course, the argument of the psychologist could very well be that poor selection techniques were used in choosing the workers for the first factory. To put it bluntly, as a group they were too intelligent for the jobs they were given and became bored. Is it the function of the industrial psychologist to devise tests so efficient that they will select Aldous Huxley's nerveless gammas so that this simplified factory will again equal the productivity of the more complex factory because it would be cheaper this way?

In the latter part of his paper Professor Viteles speaks of job satisfaction tests. He emphasizes that dissatisfied industrial workers become the focus of industrial conflict. If this concept is to be socially constructive, then the assumption must be that there is a wide enough variety of jobs available to please everybody in the population. Such a situation is exceeding unlikely, particularly during this time when a polarization seems to be at work dividing the old semi-skilled jobs between those that become very highly skilled and those that are routine, repetitive and boring. It is my own feeling that many employers are interested in these job satisfaction tests as a coefficient of the union-proneness of future employees, rather than being interested in any abstract concept of one big happy family.*

The field of human relations received its greatest impetus from the work of

* From the *Proceedings* of the September 1949 meeting of the Industrial Relations Research Association, Denver, on the subject "Psychology of Labor-Management Relations, pp. 52-54.

Elton Mayo at the then non-union Hawthorne plant of the Western Electric Company. It will be recalled that the conclusion to which Mayo came was that the group attitudes of workers were a much more important variable in determining production levels than were any of the more concrete influences with which engineers had concerned themselves—such as levels of lighting.

Mayo's empirical findings are relatively neutral. Controversy arises when management attempts to use these empirical findings for manipulative purposes. Mayo's empirical data have been used on behalf of unionism and against unionism.

Ruttenberg and Golden have noted that:

> The findings resulting from these researches and motives for union membership among workers are the same. These researches, therefore, constitute a study of the origin of labor unions.*

Scholars of industrial relations like Professor Ben Selekman of Harvard have structured a whole philosophy of union-management relations around these concepts.†

On the other hand, this technique has been used in an attempt to by-pass the necessity for trade unions. A typical example of a trade unionist's reaction to some of these techniques was likewise given by the writer at this same Denver meeting. His remarks follow:

Professor Maier had just presented a paper describing a technique of democratic decision. Workers were called upon to make a limited decision—who should come in on a regular day off. There was no question that someone would have to come in. Workers were not asked whether anyone was willing to come in, but that someone had to come in and they should decide democratically who it should be. Professor Maier had pointed out that this was not a management manipulation technique because the decision would have to be unanimous. This led the writer to give the following answer to Professor Maier.

> Mr. Maier in his paper is recommending a technique to factory managers which has been used by progressive educators ever since John Dewey wrote his first tracts on education.
>
> However, there seems to be a confusion here between the trappings of democracy and its inner substance. Maier is quite aware of this. He states that the main purpose of his technique is to deal with the how of the job rather than with whether or not the job is to be done at all.
>
> Now the essence of democracy is the diffusion of power among contending groups so that they must reach agreement in order to function. The trappings of democracy granted at the sufferance of a despot and removable at his whim represent a very transparent facade for the real thing. Maier's technique, no matter how well intentioned or sincerely offered, must of necessity degenerate into a manipulative technique. You are not asking or consulting people about what to do. You are maneuvering them so that they do what you want, but more efficiently. Perhaps such techniques are indispensable to the operation of a business enterprise. It is an open question whether or not an individual business enterprise can operate along any other but authoritarian lines. If it must, then Maier has something to offer, but this should not be confused with democracy.
>
> Perhaps I can best illustrate what I mean by citing the example given by Maier. You will recall that he describes a situation where a supervisor needed two of three girls for Sunday work. All three girls had dates, one with girls, the second with her regular boy friend, and the third with a boy of whom she hoped to make a new conquest. The supervisor called all the workers together to determine "democratically" which two of the girls should be compelled to come in on Sunday. After deliberation, the group decided that the girl who could keep her date was the girl seeking the new conquest.
>
> If that factory were organized, the problem would be handled by asking the

*C. S. Golden and N. J. Ruttenberg, *The Dynamics of Industrial Democracy* (New York: Harper and Brothers, 1942), p. 181.

†B. Selekman and S. Fuller, *Problems in Labor Relations* (New York: McGraw-Hill Book Company, Inc., 1950).

girls whether they would be willing to work on Sunday in the first place. There would be no implied assumption that the girls' dates after working hours were any less important than the employer's production problem. If the girls are not willing to work after regular working hours, the employer is expected to seek a different solution to his production problem. This makes the difference between real democracy, where power is distributed between the employer and the working force, and play-acting democracy, where all problems are solved on the basis of the satisfaction of the employer's achievement of his objectives.

Thomas Jefferson once observed that the continuation of democracy did not lie in the idyllic cooing of the lion and the lamb. It rested in the mutual suspicion and distrust of equal contending groups, neither of whom would permit the other absolute power. They would function together by compromise.

I do not mean to imply that there is no room for the industrial psychologist in the democratic scheme of things. Not at all. However, the psychologists must make up their minds within which system of values they are going to practice their techniques. Psychology can be considered among the social sciences. It is anxious to receive support, and some business spokesmen in rather unabashed terms have made clear under what set of circumstances the social scientists may expect to receive business support. They want operating techniques which will promote their own private concept of good industrial relations, that is, the relationship between the good shepherd and his sheep.

Frankly, I am suspicious of any technique which purports to eliminate all industrial conflict. What we have to know is how to handle these conflicts without rending the social fabric of the country.*

The violent reaction of trade unionists to this sort of manipulation appeared in a UAW-CIO publication:

> The gravest charge that can be leveled against these researches is that they uncritically adopt industry's own conception of workers as means to be manipulated or adjusted to impersonal ends. The belief in man as an end in himself has been ground under by the machine, and the social science of the factory researchers is not a science of a man, but a cow-sociology. Burleigh Gardner has written: "The more satisfied he [the worker] is the greater will be his self-esteem, the more content will he be, and therefore, the more efficient in what he is doing." Surely, this is a fitting inscription to go under the Model T symbol of Huxley's *Brave New World*.*

Koivisto has spelled out the issues which will dictate the trade unionist's reactions to human relations problems as follows:

> Explicit awareness of values will serve to focus attention on problems that were not previously apparent. Interpreting industrial relations in terms of a given value framework, explicit or implicit, results in the solution of the "labor problem" in terms of some ideal model, such as Simons' competitive society, Golden and Ruttenberg's "industrial democracy," or the human relations group's rule by intelligent managers armed with human relations "skills." †

This last set of values can well lead to a well-lubricated authoritarianism.

On the other hand, many constructive studies of the tensions to which industrial workers are subjected have come out of this fundamental orientation—for example, Walker's & Guest's *The Man on the Assembly Line*.‡ Such studies provide the data upon which management and labor through their respective organizations can act intelligently.

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* From the *Proceedings* of the September 1949 meeting of the Industrial Relations Research Association, Denver, on the subject, "Psychology of Labor-Management Relations," pp. 55-56.

* Dan Bell, "Deep Therapy on the Assembly Line." *Ammunition* (Detroit, Mich.), Vol. VII, No. 4 (April, 1949), p. 48.

† W. A. Koivisto, "Value, Theory and Fact in Industrial Sociology," *American Journal of Sociology*, Vol. LVIII, No. 6, May, 1953, 572.

‡ Charles R. Walker and Robert H Guest, *The Man on the Assembly Line* (Cambridge, Mass.: Harvard University Press, 1952).

Another technique which has lately received great emphasis is "communications." The trade unionist's reaction to "communications" problems is generally one of cynicism. He finds too often that the employer is so convinced of his position that he is unable to understand how anybody can take issue with it. Since he can't admit to himself that there are two points of view, he finds an expert who is willing to support his own viewpoint. The employer's failure to gain acceptance of his ideas is then regarded by him as a failure in communications. The following extract will serve to illustrate the writer's reaction:

> The Standard Oil Company of New Jersey communicates with me in two ways: as a customer and as a voting citizen. When I purchased my oil burner from the Esso Standard Oil Company (and I might add that it is a good burner), in order to keep my good will and spare me needless expense, the firm sent along with the burner a set of instructions telling me what to do should the oil burner fail to work. Permit me to observe that the rhetoric used in this communication and the illustrations given do not begin to match the slick paper on which most corporations present their public appeals against so-called double taxation. Somehow despite all these technical failures, I, along with many fellow customers of the Esso Standard Oil Company, have made it our business to understand what Esso is trying to tell us in this technical paper. We knew that the company spoke with authority; we had implicit faith that the engineers who drew up this paper knew about what they were talking.
>
> I assume that many of you in the audience shared this feeling when you have purchased a toy which you had to assemble for your youngster in accordance with a set of instructions written in pure gibberish. You have always made it your business to understand these directions. You have faith in the mechanic who composes these directions. He might not know how to write aesthetically, but he knows how to put the toy together.
>
> How many of us share the same faith in the authority of the company when it attempts to present its side of an anti-trust suit or its interpretation of the effect of a price regulation or its tax argument? The breakdown in communication, if it is a breakdown in communication, does not arise because the material is unskillfully presented. It breaks down because we are not at all certain that the company knows about what it is talking. In other words it is not a problem in communication; it is a problem in resolving a conflict in ideas. And as long as we attempt to resolve conflicts in ideas by calling them failures in communication we are going to be frustrated.*

10. THE LEGAL STATUS OF INDUSTRIAL ENGINEERING TECHNIQUES AS SUBJECTS OF COLLECTIVE BARGAINING

The first problem that unions faced in handling production standards disputes was to establish the area as a field of collective bargaining. The whole philosophy which we have reviewed was the basic rationale to establish this right. Part of the history of the recognition and enlargement of this right can be traced through the National Labor Relations Board cases, the War Labor Board cases, and voluntary arbitration decisions in this area.

The legal approach to this problem is hardly a fruitful way to promote good understanding. It is useful, nevertheless, to understand what these obligations are even if the engineer wants to prepare himself for nothing more than a fight.

Section 8 of the National Labor Relations Act provides:

> (a) It shall be an unfair labor practice for an employer—(5) to refuse to bargain collectively with the representatives, his employees. . . .†

The N. L. R. B. and the courts have supported the position under this clause that wage information which is necessary to the union for intelligent bargain-

* W. Gomberg, discussant, *Proceedings of the IRRA Annual Meeting,* Dec. 1952, pp. 151-152.

† Section 8(a)(5) of the NLRA (Taft-Hartley Law).

ing on the issues raised in negotiations must be supplied to the workers even when the contract is silent on the subject. The Board has interdicted unilateral changes affecting wages and has drawn no distinction in situations in which a wage incentive payment plan is involved and situations in which a wage incentive payment plan is not involved.

For example, in *Mason and Hughes, Inc.*, 86 N. L. R. B. 848 (1949), the unilateral installation of an incentive plan was declared in violation of Section 8(a)(5) and failure to answer inquiries about the plan were tantamount to withdrawal of recognition from the Union.

On the other hand, the Board ruled in *Libby, McNeill and Libby*, 65 N. L. R. B. 873 (1946), that the employer's unilateral establishment of a wage incentive plan was found to be legitimate. The union had accepted the plan for three years and then sought its elimination through collective bargaining. Failing in this approach, it then attacked the initiation of the plan. The Board held that "the attack comes too late," and there was no refusal to bargain.

Some other examples of management unilateral action which the Board has declared illegal follow:

1. Making unilateral adjustments in piece rates or unilaterally determining and establishing the amounts of piecework rates.*
2. Refusing to discuss the elimination of its incentive plan and promulgating its extension to other non-incentive employees.†
3. Threatening to cut the piece rate if the union won the election.‡
4. Unilateral institution of a wage incentive plan when the collective bargaining agreement provided that such a plan might be operated if adopted by mutual agreement of management and the union shop committee.*

* *Tower Hosiery Mills, Inc.*, 81 N. L. R. B. 658 (Feb. 1949). *Top Mode Manufacturing Co.*, 97 N. L. R. B. 1273 (Jan. 1952).

† *H. R. Terryberry Co.*, 88 N. L. R. B. 642 (Feb. 1950).

‡ *Dovedown Hosiery Mills*, 102 N. L. R. B. No. 65 (Feb. 1953).

One of the principal methods that have been used to enlarge the inclusion of wage incentive payment plans and job evaluation plans in the area of collective bargaining has resulted from the doctrine of the employer's obligation to furnish wage information to the union.

The first wage information case arose in 1942. It did not involve a request for either wage incentive or job evaluation information, but the reasoning in the case was subsequently applied in a long line of cases, many of which did involve such requests. The case involved the Aluminum Ore Company. Here the Board upheld the union's right to request a wage history of the employees in the bargaining unit, including, by name, their rates of pay, job classification, and wage changes over the previous two years, and denied the firm's contention that this information was confidential. The Court of Appeals, in enforcing the Board's order to comply with the Union's request, said:

> [Collective bargaining] contemplates exchange of information, ideas and theories in open discussion and an honest attempt to arrive at an agreement. . . .
> Again we cannot believe that it was the intent of Congress in this legislation that, in the collective bargaining prescribed, the union, as representative of the employees, should be deprived of the pertinent facts constituting a wage history of its members. We can conceive of no justification for a claim that such information is confidential. Rather it seems to go to the very root of the facts upon which the merits were to be resolved.†

The review of the employer's obligation to furnish wage information will be divided into two parts. The first will concern itself with the application of this obligation to wage incentive pay-

* *Morgan Co. Inc.*, Wis. ERB (1940), 6 LRRM 639.

† *Aluminum Ore Company*, 39 N. L. R B. 1286, enforced 131 F.2d 485 (C.C.A. 7th).

ment plans and production standards disputes. The second, to job evaluation and job classification disputes.

Employers have relied on a variety of reasons for failure to furnish wage data for collective bargaining sessions, with mixed results. For example, in the *Crompton-Highland Mills Case*, the union, knowing the schedule of rates and current payments under the firm's point system, requested information on the method of determining the point, point standards, and job specifications. The employer refused to reveal this information but invited the union to make its own studies. The Board, reversing the trial examiner's findings, held that the firm's refusal to comply with the union's request was not in bad faith.

> In view of the [firm's] invitation to the Union, to conduct its own engineering studies at the plant, and under all the circumstances of this particular case, including the evidence of substantial counter-proposals on many other issues, we find that this part of the respondent's conduct was *not* violative of Section 8(5) of the Act.*

On the other hand, the Board ruled:

> [The] employer refused to bargain by refusing request for information on production standards on government contracts, the methods used to calculate individual earnings, pay rates and incentives bonuses.†

Similarly, it ruled in the *Vanette Hosiery* case that:

> [The] employer refused to bargain by refusing to produce the information requested by the union concerning the piece and hourly rates of certain employees. The union requested (a) the piece and hourly rates in effect at the mill on all job classifications as of that date, and (b) the average hourly earnings for each department compiled on a 40-hour work week basis.‡

* *Crompton-Highland Mills, Inc.*, 70 N. L R. B. 206 (August 1946).

† *Dixie Manufacturing Co. Inc.*, 79 N. L. R. B. 645 (Sept. 1948).

‡ *Vanette Hosiery Mills*, 80 N. L. R. B. 1116 (Dec. 1948).

Again, as late as 1952, the Board ruled that the:

> [The] employer refused to bargain by refusing to supply a list of piece rates needed for bargaining.*

Significantly, however, in *Otis Elevator Company*, 102 N. L. R. B. 72 (Jan. 1953), the firm, in handling a grievance, refused to furnish or allow copies to be made of its file on the production standard for one of its operations. The union's request to bring in its own time study man to conduct a study of the job was also turned down. In both instances, the employer was found to have violated Section 8(a)(5).

The ruling in the Otis Elevator Case represented a marked departure from the ruling in the Crompton Highlands Case. It will be noted in the Crompton case that the offer of the company to permit union time study men to make their own studies in the plant freed the company of any obligation to furnish the company's time study data to the union.

The Otis Elevator Case obligated the employer both to furnish the company's data and simultaneously to permit the union to make its own studies. We now turn to a review of the employer's obligation to furnish job evaluation and job classification material.

The Board ruled that:

> [The] employer refused to bargain by refusing to supply the salary and number of points in its job evaluation plan for each of the employees in the unit.†

This right of the union to secure job evaluation data from the company is emphasized again, for example: A bonafide delay in getting the data requested is recognized by the Board. Thus, in *Old Line Life Insurance Co. of America*, 96 N. L. R. B 499 (Sept. 1951), the Board held that the employer's failure to fulfill its contractual commitment to draft a clear-cut definition of the work

* *Texas Foundries, Inc.*, 101 N. L. R. B. 249 (Dec. 1952).

† *The B. F. Goodrich Co.*, 89 N. L. R. B. 1151 (May 1950).

requirements of the several classifications under its job evaluation plan was not a refusal to bargain in bad faith. *For the employer's omission "was not motivated by a desire to delay or prevent bargaining on the matter in question." The preparation of the plan was time-consuming and the employer has promised to present it for consideration as soon as ready.*

The trial examiner of the Board in the Electric Auto Lite case spelled out the importance of this obligation to furnish the union with wage classification information. He stated that:

> [The Union] could not intelligently represent the employees in the bargaining negotiations for a general increase then under way without knowing their current wage rates.
>
> Furthermore, as the recognized bargaining agent, it was the Union's duty to make inquiries . . . in order to determine whether the salaries and merit increases were within the agreed range [25 union members]. . . . The small size of the unit is material only as emphasizing the reasonableness of the Union's request and the ease with which the Respondent can comply. There is and can be no claim that compliance would be "so burdensome or time consuming as to impede the process of bargaining." . . .*

Finally, the Board ruled in the Montgomery Ward case that:

> The employer refused to bargain, announcing a new job evaluation plan 5 days after the complex proposal, many months in preparation, had been submitted to the union.†

Thus it can readily be seen that the National Labor Relations Act specifically includes the techniques of job evaluation, wage incentive payment plans, and the underpinning production standards within the area of collective bargaining. This conclusion has been affirmed by the courts.

* *Electric Auto Lite,* 89 N. L. R. B. 1192 (May 1950).

† *Montgomery Ward and Company,* 90 N. L. R. B. 1244 (July 1950).

The National War Labor Board's approach to these techniques is of historical interest, although its decisions possess no statutory force. A review of these decisions is nevertheless useful because they set the thinking for many current arbitration decisions.

With the increased interest in wage incentive plans during World War II, the National War Labor Board soon found it necessary to develop wage incentive payment plan standards for approval. Executive Order No. 9328, the "hold-the-line" order of April 8, 1943, empowered the Board to authorize "reasonable adjustments of wages and salaries in the case of . . . incentive wages or the like."

Shortly thereafter, in September, 1953, the first plant-wide incentive plan case, *Grumman Aircraft Engineering Company,* came before the Board. In this case, the Board established the principle that:

> The basis of any incentive plan is whole-hearted acceptance of those directly affected. The Board will not order an incentive system in a dispute case It will act only upon voluntary submissions made by an employer and joined in by a union where it represents the employees.

This principle was later reaffirmed in a unanimous resolution announced on October 2, 1943:

> Consideration by the National War Labor Board of proposed wage-incentive plans will be limited to voluntary submissions by employers and to joint submissions agreed to by employer and union in each situation in which a union is the collective bargaining representative of the employees. Incentive wage payment programs will not be ordered in dispute cases since that would be incompatible with the need for cooperative effort which is basic to the success of such programs.

The policy with respect to certain new plans was thus clearly delimited.

The Board policy on changes in established plans was never embodied in a resolution or statement. Its position, however, is clear from a number of

cases. In *Riverside and Dan River Cotton Mills*, (WLB) 1943, the Board recognized "management's function and responsibility to initiate technological changes and make method improvements with the understanding that changes affecting working conditions, wages, or security of the employee will be subject to review and agreement between the company and the union." The Board felt in this and a series of other cases, that the problem was adequately handled if the parties:

1. Handled questions of changes through established grievance procedure.
2. Had a joint discussion of rates prior to institution.
3. Bargained collectively.
4. Had a trial period of operation.
5. Resorted to arbitration if disputes could not be settled by collective bargaining.

Thus the right of the union to challenge management's unilateral decisions with respect to production standards under established systems was limited to the contractual grievance procedure and arbitration machinery. If, however, the contract provided for *joint* settlement of piece rates or production standards, then the Board upheld the contractual provisions. (*American Wire Cloth Mfg. Assn.*, WLB 1944).

The Board faced a somewhat different problem, however, when faced with a contract giving the employer the right to institute such a plan without union consent. In the case of the Kosmos Timber Co., an order directing the firm to discontinue a piece-rate system was vacated since the contract established the employer's right to maintain such a system.

This decision stemmed from the Board's policy to preserve established collective agreements.

Condition number 5, above, calling for the settlement of production standards disputes by arbitration, is particularly significant. Following the war, organized management through President Truman's Labor Management Conference attempted to define the setting of the standard as a management function with arbitration ruled out as a terminal point. This was an attempt to roll back the Board doctrine that had become part of postwar thinking on collective bargaining.

11. ARBITRATION DECISIONS

11.1 GENERAL APPROACH

Arbitration decisions with regard to wage incentive and job evaluation programs have not been consistent. In part, this inconsistency is due to the arbitrator's conception of his role in the dispute. One arbitrator will insist on a highly technical interpretation of a contract, whereas another will seek an interpretation that will maintain industrial harmony and further mutual understanding. Many decisions have run counter to the stream of N. L. R. B. decisions. Such decisions are possible because the N. L. R. B. will not ordinarily step into a dispute over an interpretation of contract, particularly when the grievance procedure calls for arbitration, as it does in most contracts today. Since contracts make the arbitrator's award final and binding on both parties, decisions can seldom be challenged successfully.

11.2 THE NATURE OF MANAGEMENT'S RIGHT TO SET PRODUCTION STANDARDS

The widely publicized decision that ended the four-week strike at the Ford Motor Company in 1949 spelled out in detail the nature of management's right to set production standards.

> . . . The "right of the company" [to establish, determine, maintain, and enforce standards of production] which is "fully recognized" is not a right to make a final and binding determination. It is not like other "rights" specified in Article IV, as for example, the right to "decide the number and location of plants" or the "products to be manu-

factured" or the "schedules of production" or the "starting and quitting time." As to these matters, the company may make *final* determinations which the union must accept for the term of the contract and which may not be made the basis of strike action during that term. Such is not the case with respect to production standards. There the right "to establish and determine and to maintain and enforce" is more in the nature of *a right to* initiate. . . .*

Turning to the specific issue before it, the arbitration panel then ruled that:

> Under contract which gives the company the right to maintain and enforce standards of production, the employer may operate its production lines at a speed in excess of the desired production schedule. However, it must seek to make each employee's work assignment as measured by standard work minutes equal to or within actual production cycle time available to him. In cases where the speed of the production line results in requiring employees to regularly work at a speed above standard, the *parties should work out a solution to fit the situation.*†

In other words, they must bargain out a mutually satisfactory solution. The obligation to furnish information to the union on the operation of wage incentive payment plans and the setting of production standards has been sustained in the following cases:

1. *Kendall Mills,* 8 LA 307 (August 1947)

The contract provided that the employer should discuss proposed changes in job or work assignments, workloads, and job rates with the union's shop committee, with a view to reaching an agreement on such changes. The union is entitled to job descriptions for all job classifications in the bargaining unit, since it is "a reasonable request and would facilitate the operation of the collective bargaining agreement."

2. *International Harvester Co.,* 14 LA 63 (January 1950)

Since the contract provided that in disputes over piece rates the employer must furnish the data upon which the rate in question was established, the employer must furnish the union with the original time studies requested, showing the observed times and standard times fixed for each element in operation. Contention is rejected that the employer need furnish only the standard time fixed for the entire operation because that is what the rate is based on. Confusion arises when the problem of unilateral action by management in the administration of the plan takes place; for example, the following two cases sustain unilateral management action.

3. *Champion Lamp Works,* 11 LA 703 (October 1948)

Under contract giving the employer exclusive rights to manage the plant, the employer may change the speeds of the machine at his discretion so long as the wage benefits of the contract are not negated.

4. *Thor Corp.,* 16 LA 770 (May 1951)

The contract provided that when the employer contemplates increasing the speed of a machine, the union must be called in "to determine whether or not there is a necessity for changing the piece rate." The employer is not required to obtain union approval of either the new speed or the new rate. The determination of whether the machine speed should be increased and what specific rate should be paid for the job are the sole prerogative of management. On the other hand, here is an example where such action was limited.

5. *Huffman Mfg. Co.,* 17 LA 293 (September 1951)

The employer has the right to set a higher production rate for assembly line without increasing the pay of the employees provided that the increased output does not require employees to produce greater than 125 per cent of base rate, which is the maximum production

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* By permission from *Problems in Labor Relations,* by Benjamin M. Selekman, Sylvia K. Selekman, and Stephen H. Fuller. Copyright, 1950. McGraw-Hill Book Company, Inc., pp. 338, 339. (Italics in last sentence by author.)

† *Ford Motor Co.,* 12 LA 949 (July 1949).

rate that can be required under the past practice of the parties.

Private arbitrators differ in their interpretation of the rights of the union under job classification schemes. Most of these decisions depend upon the contract and the personality of the arbitrator. For example, in the case of General Motors, the arbitrator ruled that:

> Management has the right to set up new classifications, but does it have the right to take such action without prior consultation with the representative of the employees? The answer is found in the rulings of the N. L. R. B. and the Courts which have consistently held that an employer in taking an action affecting wages, hours, and other conditions of employment should consult the union.*

The arbitrators ruled similarly in the case of the Armstrong Rubber Co. and Librascope, Inc. The decisions state that:

> When the contract provided that the employer must "meet with and bargain with" the union on "all matters" pertaining to wages, hours, and conditions of employment, it was a violation for the employer to establish a new job classification and rate without bargaining; discussion of the change under the grievance procedure after new classification and rate became effective is not sufficient.†
>
> Although the contract gives the employer exclusive rights to determine the methods and means of manufacture, it does not give the employer the unilateral right to establish new job classifications as the contract also provides that "additional occupational classifications may be installed by the union and the company."‡

Thus, in every case, the careful circumscription of management's prerogative in this field leads it to share the function with the union. The kind of decision that can be expected under similar contracts, however, where the arbitrator takes the legalistic rather than the operating approach is seen in the case of the Great Lakes Carbon Corp. Here the arbitrator ruled that:

> In the absence of a clause to the contrary, the employer has the right to unilaterally abolish two job classifications and establish a new classification following the introduction of new equipment. The clause providing that "nothing contained herein shall prevent the company, in conjunction with the union, from establishing new classifications," does not expressly require joint action.*

A similar legalistic approach to information disclosure is found in the case of the Borg-Warner Corporation.

In Borg-Warner Corp. Case, 9 LA 901 (1948), even though the contract provided for negotiations to eliminate inequities in the application of a new job classification system, the employer's refusal to furnish the union with its point evaluation system on which job classifications are based was not a refusal to bargain. "It is . . . clear that the parties are entitled to develop information independently and for the purpose of pressing their respective positions." Neither set of data is binding upon the parties. When the employer rejects the union's proposal in light of its own job evaluation chart, the union can persist in its position and request the employer to give a more revealing answer or advance its case on the basis of its own job standards.

The conclusions to which we come after reviewing this legal treatment is that unions in the future are unlikely to sign contracts that waive rights guaranteed to them by past decisions of the National Labor Relations Board. A union may find itself in the anomalous position where it is entitled to all the information about a time study plan

* *General Motors Corp.*, 7 LA 368 (April 1947).

† *Armstrong Rubber Co.*, 18 LA 90 (January 1952).

‡ *Librascope, Inc.*, 18 LA 539 (March 1952).

* *Great Lakes Carbon Corp.*, 19 LA 797 (January 1953).

before it has signed its first contract, but because it was not careful in delineating its time study rights under the contract a legalistically minded arbitrator is able to take away something from it which it had before the agreement. As we have seen, the N. L. R. B. will not restore rights waived by the union in a voluntary contract. This waiver, of course, can only happen once. Under the circumstances, the engineer would be wise to reconcile himself to the fact that the union will be a party to all his techniques. It is to his advantage to learn what practices they are ready to accept.

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NOTES